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FOUNDATIONS OF THE UNIVERSE

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A popular series treating their influence on the development of civilization

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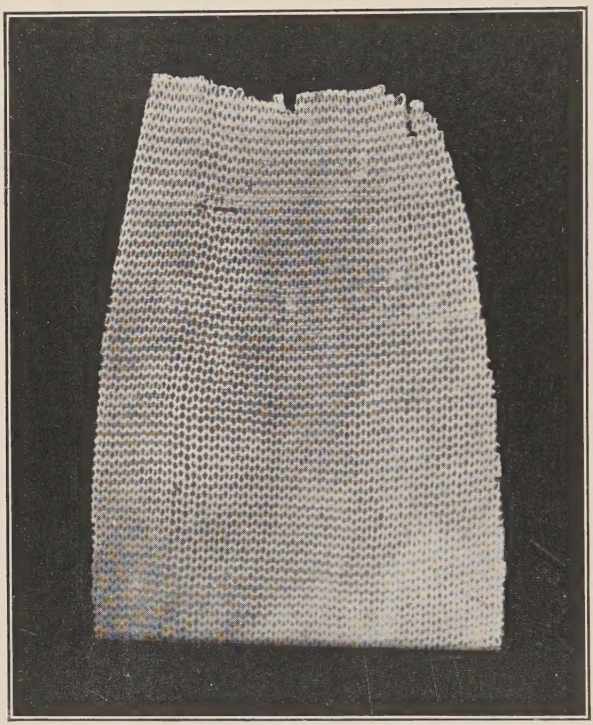

Frontispiece. A gas-mantle can photograph itself. This picture was produced by leaving the ash mesh of a gas-mantle in contact with a photographic plate for ten days. The mantle contains thoria — thorium oxide — which is radio-active. The radiation emitted by the disintegrating thorium atoms affects the photographic plate so that photographs like the above are obtained.

FOUNDATIONS OF THE UNIVERSE

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PREFACE

If we traverse in our imagination the pathway over which Man has struggled, we arrive at the conclusion that knowledge of the physical world has been the foundation of civilization. We also note the ever increasing momentum of scientific progress and of its applications. Everyone is vitally interested in science, whether he is consciously so or not. He cannot escape the influence of such knowledge as long as he is a part of civilization. Even the savage does not drift through life entirely without the use of at least a scanty knowledge of Nature. Man is unable to alter the laws of Nature, but he can utilize them. He cannot avoid their ultimate victory over him, but he can often step out of their way during his brief sojourn as an Earth-Being.

"Man only, — rash, refined, presumptuous Man —
Starts from his rank, and mars Creation's plan!
Born the free heir of Nature's wide domain,
To art's strict limits bounds his narrow'd reign;
Resigns his native rights for meaner things,
For Faith and Fetters, Laws and Priests and Kings."

These lines provide much to think about in regard to Man's place in the scheme of things. At least they remind us that we have stepped from the rank of Creation's scheme. We are stepping further and further from the rank as our knowledge increases. However, we are not free and we are handicapped by the limitations of our human senses. With respect to the physical world as we know it, we stand midway between inconceivable distances, but we have already achieved much in spanning them. In the far-off stellar crucibles we see the same laws being obeyed as in our laboratories. As we trace matter down to the almost infinitesimal constituents

of the extremely minute atom, we find that apparently it does not exist at all as the realistic matter which we have supposed it to be. There at its very foundation it seems to consist of electric charges which probably simulate the motions of celestial bodies. Throughout this inconceivable range in magnitude from atoms to stars the same physical laws seem to reign. But the most marvelous revelation is the wonderful unification of apparently unrelated phenomena. Long ago we became convinced that Nature was orderly and perhaps simple. It is becoming more and more certain that the apparent complexity of Nature is due to our lack of knowledge. As the picture unfolds it promises a marvelous simplicity.

It is the aim of this book to present popularly and systematically the picture of the foundations of the universe as it now appears. Owing to the magnitude of the subject, it has not been practicable to tarry long over any portion of it. Many details have been purposely omitted, because of lack of space. No claim to completeness is made although the author is not aware of any important foundation-stone that has not been considered. It has been the aim to confine the discussions chiefly to established facts and to give only glimpses into the realms that are speculative at present. For obvious reasons mathematics has not been utilized notwithstanding the difficulty of explaining some physical processes without this wonderful medium of expression. As a consequence some portions of the picture may be blurred because words are inadequate substitutes for mathematical equations. It is hoped that this book will be interesting to the general reader, helpful to students of science, and even to specialists in science whose own fields are somewhat removed from foundational physics.

M. LUCKIESH

May 12, 1924

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FOUNDATIONS OF THE UNIVERSE

Chapter I

MEN, ATOMS, AND STARS

My friend or your friend marvels nightly at the wonders of the latest scientific achievement which has swept over the civilized world. His radio "receiving set," without any material connection with the outside world, accurately reproduces for him the music or speech which is delivered to a "sending set" located a thousand miles away. This to him is marvelous, perhaps awesome, and in most cases profoundly mysterious. But let us detach him from the radio and take him to a window. We point to that brilliant star, Sirius, and ask him if he sees it. Of course, he sees it, but "What of it"? he asks. Seeing the light of that star is even more wonderful than hearing music transmitted a thousand miles by "wireless." Let us see if we cannot convince him.

Sirius is 500,000 times farther away from us than the sun is. It is at a distance of 54 million million miles. It takes light nearly nine years to travel the distance and the velocity of light according to modern views is the highest attainable. Furthermore, the light that travels from Sirius to our eyes is electromagnetic energy in the form of waves similar to those intercepted by the radio set. The only difference is in wavelength or frequency. Off there at that almost inconceivable distance is Sirius, a station sending forth electromagnetic waves of such frequencies or wavelengths as are within the range for which our eyes — the radio receiving sets of the

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human body — are tuned. This is not a mere analogy. The two cases are practically identical from a physical viewpoint.

Minute particles of electricity — electrons — are playing a vital part in the radio tube. They are one link in the chain of reception and transformation of invisible electromagnetic radiowaves into audible sounds. Out there at such a tremendous distance that it would take the fastest airplane 25 million years to travel that far, are electrons in the atoms of the elements of which Sirius consists. These are sending forth electromagnetic energy to be *seen* by us. Each atom operates exactly like any other of the same element, sending forth electromagnetic waves of the same frequencies. Here on Earth by means of the spectroscope, we measure the wavelengths and tell what the elements are that are sending their wireless messages to us. From the viewpoint of the physical world, signalling to Mars would be but a commonplace achievement.

All around us are wonders just as surprising. Most of them are passed by without interest because they are not understood or because they are commonplace experiences. However, the most wonderful and stupendous picture is the physical universe. Nothing can excel it in magnitude. Each detail is interesting in itself, but the dovetailing of the details gives us not only a picture of great magnitude, but also one of surprising harmony, for there is unity in the whole.

Our interest in the physical world generally is not so much in itself, but in our relation to it. Atoms and stars, their compositions, properties and relations, are the physical universe. Man is incidental and of no influence or consequence. He finds himself in this physical world and strives to learn something of the mechanism. He naturally desires to know what "makes it go" and wishes to understand its laws so that he may harness them to his advantage during his so-

journ. What an insignificant mite he is and what an instant of time is occupied by his journey in this physical world!

But here, we are not so concerned with man's insignificance as we are with the confusion which he introduces into the universe, for man himself is the cause of much of the apparent complexity of the physical universe as it appears to him.

Man's contact with the physical world is complicated by the multiplicity of his senses and is limited by the capabilities of these sense-organs. We can see light; hear sounds; feel temperatures; experience weights and forces. The senses involved divide the physical phenomena into such branches as optics, acoustics, heat and mechanics. We have no special sense-organ for the phenomena of electricity and magnetism which are more foundational from the viewpoint of the physical universe than light, heat, and mass. The picture of Nature that we obtain through our senses is a subjective one. It is not the real fundamental one. Although without these senses we would have no doorways from which to view the universe, they complicate matters by giving us a picture of a subjective world. We must eliminate the prejudices of these senses before we can develop a true picture of the objective or physical world.

As we look downward from the present heights of scientific achievement we cannot help wondering at the slow progress of science during the early centuries when civilization in many respects had attained great heights. The scientific achievements of the first quarter of the present century compare favorably with the aggregate of all the centuries preceding. The wonderful practical applications of electricity have nearly all appeared during the past fifty years. The science of electricity is only about a century old. It is true that earlier centuries had marvelous men who helped to lay the foundation upon which later men built, but much of the

foundation was quicksand. A few men built well, considering the paucity of authentic data. Roger Bacon lived in the thirteenth century and Copernicus was of the fifteenth century. But it was the sixteenth century with such men as Gilbert, Tycho Brahe, Galileo, and Kepler that first witnessed a great deal of advancement in physical science that was to supply foundations of more or less permanency. Scientific achievement was ever gaining momentum, but it was still feeble and uncertain. There was too much speculation and too little experimentation, but fortunately the proportion was to change in the seventeenth century with such experimenters as Torricelli, Boyle, Huygens and Hooke appearing on the stage. Then came Isaac Newton, eclipsing all his predecessors.

There is no doubt that scientific achievement before Newton's time is insignificant compared with that which has accumulated since the sojourn of that great man. Naturally we wonder why the great minds of earlier centuries in Greece, in Rome and elsewhere achieved so little in unravelling the mysteries of the physical universe. We cannot believe that there were not mighty intellects in those centuries and fortunately such an assumption is unnecessary. The reason for the slow progress in science up to Newton's time and for the rapid advances in the past century is not found in *mind,* but in *method.* Now we build theories only upon a reasonable foundation of facts. Experimentation is the watchword of modern science. This method yields knowledge of the physical world, which is used for building the solid foundations of theories. In earlier centuries the great minds theorized without many facts and the result was largely uncertain speculation. Science has learned a great and lasting lesson which would be beneficial to all given to theorizing without a "working knowledge." As we look backward we see that the earlier peoples cheated themselves out of many things

we now enjoy, by misplaced faith, by scorning experimentation and by trying to build without knowledge. What a relief the present age would enjoy if reformers, politicians and many others would profit by what science has learned and would begin with facts instead of theory.

Let us not be misunderstood. Theory is the greatest tool that science has had. It even exceeds experimentation in value. The great epochs in scientific progress which have changed the course of thought and development have been theories built by mathematical treatment of the physical facts yielded by experimentation. For example, Newton contributed the theory of gravitation; Maxwell the electromagnetic theory of light or radiation; Planck the quantum theory of energy; Einstein the theory of relativity. These are conspicuous milestones along the highway of scientific progress.

Let us take a glimpse of scientific work as it is achieved in modern times. Here and there we have experimenters penetrating the unknown. These scouts bring back many authentic data. Various branches of physical science grow here and there. When enough data have accumulated some kind of unity may be constructed. Eventually a great mind comes along and erects a structure from these facts by arranging them systematically and cementing them together with philosophy and mathematics. If the facts are sufficiently authentic and complete, the structure is a theory. It remains so until all the gaps have been filled. Perhaps some alterations must be made to admit new data. If, as is often the case, the erected structure contains a great many gaps and some misfits, it is better named an hypothesis. It retains this name until it is safe enough to be termed a theory. The gaps in the structure are the predictions of the incomplete assembly and scientific men set about to ascertain their validity. For example, expeditions set out for the southern hemisphere

in the midst of the World War in order to determine during a solar eclipse the validity of Einstein's prediction that light from a star would be bent from its path due to the gravitational force of the sun. It was. During the construction of a theory it is often necessary to make alterations and to add final touches until finally we behold a beautiful structure of perfect unity of harmonized facts. Obviously, attempts at hypothesis and theory are necessary. Otherwise the data of experiments would merely accumulate without unification.

Many of the so-called theories which appeared in earlier centuries are misnamed. They were little more than speculations because of the scarcity of authentic observational data. Many of them are interesting and even fascinating. They prove that great minds and thoughtful men existed throughout the ages. Some of these speculations hit close to the truth as revealed by the facts garnered by later experimenters. But the hits were mere accidents for the most part. Just as the fertile imagination of Jules Verne pictured flying-machines and submarines, some of the earlier speculators pictured possibilities which are now known to be realities. It is a popular pastime among superficial writers to credit some of the early speculators with uncanny insight and foresight, but this is unwarranted. Given enough speculations, particularly when these are the products of great intellects, some of them are bound to strike close to the truth.

Thoughtful men of all times have recognized that the physical world is more likely to be simpler than it would appear to man with scanty knowledge of its mechanism and with several inadequate sense-organs. Simplicity appeared more likely than complexity. Harmonious cosmos appeared more likely than discordant chaos. Basing their speculations on these reasonable assumptions some of the earlier philosophers drew

word-pictures that are quite close to the realities as we now know them to be. For example, Democritus (460–360 B.C.) developed certain principles which, after twenty-four centuries, can be made to fit the facts by slightly modifying them. He concluded that the only existing things are atoms and empty space and that nothing existing can be destroyed. He struck close to the truth of the atomic and the electronic theories as they have recently been developed. He tried to construct a picture in which motion was the only physical phenomenon. While it now appears that physics cannot be reduced entirely to mechanics, some of the speculations of Democritus are substantially correct. However, it would be unfair to those modern philosophers such as Newton, Maxwell and Einstein, who builded upon known facts and who coördinated authentic data by mathematical genius, to credit early philosophers with comparable achievements. The earlier ones speculated thoughtfully without being fettered by a multitude of facts. The modern ones must develop principles which harmonize a vast amount of data.

Another difficulty which has hindered man in forming a true picture of the objective world is that mixed blessing — egoism. In early centuries he could not escape from the false assumption of his own preëminent importance and these same shackles are still prejudicing the observations of most persons. Under this handicap it is not surprising to find man placing himself at the center of the universe. When he began to speculate in regard to the motion of heavenly bodies naturally he conceived them as in motion around the earth. The latter was the stationary center of the cosmos. Many brilliant men were to suffer persecution for striking at this bigotry by attaching less importance to man and the earth by giving to the latter a motion and an importance comparable with the other heavenly bodies.

Pythagorean philosophers suggested a system in which the earth was not the center of the universe. It was not accepted, but the seed was sown which 2000 years later inspired Copernicus (1473–1543) to develop the system of planetary motions around the sun. This was destined to form the foundation of an accurate picture of our solar system. Galileo (1564–1642) was just the man to take up the Copernican theory. With the astronomical observations of Tycho Brahe (1546–1601), with better telescopes, with the friendship of Kepler (1571–1630), and with his own genius, it is not surprising that he placed the Copernican theory on a solid foundation from which it was never to be shaken.

Scientific men encountered obstacles in those days besides those naturally found in their physical researches. Throughout fifty years this great scientist successfully battled the churchmen and others. The controversy of Galileo with the Inquisition is famous. This searcher for truth was confronted by the hordes of bigotry and ignorance. Finally he was haled before the Inquisition and the judgment of the court was that his claim to the effect that the sun was in the center of the solar system and that the earth was not the center of the world was "absurd, philosophically false, and formally heretical because it is expressly contrary to the Holy Scriptures." In appreciation of his great contribution to our knowledge of the foundations of the universe we cannot blame him when finally confronted with the terrors of the Inquisition, he recanted his doctrines. But the latter were the truth and they lived until a time when they could be openly proclaimed.

The foregoing is introduced to show what hindrances were encountered by scientists of the past. Fortunately, bigotry and ignorance no longer hinder scientific progress. But the new world did not escape the final struggles of that controversy. Perhaps it will shock some readers to learn that

a half century ago a state university in the Middle West drove a young teacher of physics from the school because he dared by experimentation to lift the veil from Nature to view the "sacred realm." There is in print a record of this persecution and controversy which took place in the latter part of the nineteenth century. The young man lived to a moderate old age and passed away only recently after a successful life of contribution to physical science.

Although such bigotry and ignorance have ceased to handicap scientific research, man finds it difficult to step aside and view the physical world quite apart from himself. For example, he cannot submerge his own dimensions and those of his daily contact. For this reason the distances in the stellar universe appear inconceivably large and those of atomic structure appear infinitely small. These difficulties are natural and man is wholly above criticism in this respect. Nevertheless, in order to obtain a proper view of this wonderful mechanism he must transport himself in his mind's eye to great distances and must contract himself into the atom. He will see wonderful systems of bodies in orderly motion in both cases. It is a good exercise to attempt to conceive limitless space bounded by nothingness which extends forever. Out in the stellar universe he finds a great void inhabited by heavenly bodies relatively "few and far between." In the atom he finds the same condition.

To the uninitiated person a glimpse of the night sky reveals what appears to be countless heavenly bodies scattered in confusion. Ask him to count the stars and he would be awed at what would appear an impossible task. Still, from a single viewpoint a person can see with the unaided eye only about three thousand stars. All the persons over the entire face of the earth from pole to pole can see less than ten thousand stars. Galileo's telescope with its objective lens

$2\frac{1}{4}$ inches in diameter revolutionized human thought because it multiplied the number of visible stars a hundred times. Each increase in diameter of lens or reflector up to the 100-inch Hooker telescope at Mount Wilson Observatory has revealed many more stars. Add to those the records of long photographic exposures and we have a billion stars revealed. How many stars are still behind the veil, of course, is not known, but there are many no doubt.

Although the telescope has increased the complexity of our visible universe by revealing millions of its inhabitants, it is also simplifying the physical world by revealing the motions, the constituents, the relations, and the forms of the celestial bodies. Some of the experiments that the physicist would like to perform in the laboratory, but cannot owing to his inability to produce the proper conditions, are now daily and nightly performed by viewing the phenomena in those far-off celestial laboratories of nebulae, of comets, of glowing gaseous stars, of very hot suns, etc. The physicist now studies the spectra (the electromagnetic waves) emitted by elements at high temperatures as yet unattainable in man-made laboratories. He finds new elements in far-off stars before they are found on earth. He discovered helium in the sun twenty-eight years before its detection on earth. The telescope and its accessories, especially the spectroscope, have proved that the same elements are scattered throughout space; that all celestial bodies have a common origin. This is simplification indeed. And finally he is learning much of the evolution of matter from the myriad stars of all stages of evolution and levels of temperature.

If we reverse the telescope in our imagination, the stellar universe or particularly our solar system gives us a rough model of the atom. The microscope fails us long before the smallness of molecules or atoms is reached, but by indirect

methods a still smaller particle, the electron, has been isolated and measured. The atom is now known to consist of a positive nucleus — protons — and negative particles of electricity — electrons. Usually electrons are considered to revolve around the nucleus, the number varying with the element. Thus everywhere from stellar space to atomic space we find bodies in motion, and when we think of how small the protons and the electrons are, we can see that Democritus came close to the mark in his bold speculation which reduced physical phenomena to a single one — motion.

As we take these intimate peeps into the mechanism of the physical world perhaps we are reminded of an attitude which crops out here and there. The scientist by his cold analysis is often considered to be robbing us of the pleasure that awe and mystery give. The artist often shows this attitude plainly. But knowledge is safer than ignorance in our present civilization. This is one of the defenses of the scientist if he needs any. As for the validity of the contention that knowledge lays Nature bare, thereby robbing it of its beauty and us of the pleasure of awe and mystery, it falls down completely. To know the reason for colors does not rob us of the pleasure that color gives. As for awe, the disintegration of radium, the mechanism of the atom, the motions of the planets, the great torches of flame which shoot out from the sun, the plunging of our own planetary system toward the galactic and many other facts of the physical world are more awesome than any observations through the eyes of ignorance. As for mystery, plenty remains. With each addition to the area of knowledge the horizon of the unknown grows larger. Science only replaces one mystery with another of greater magnitude. Some day possibly science will have revealed everything, but we have no need to worry on that score. We shall not see that day and if anyone ever does, it is

quite likely that the compensation of knowledge will suffice for the disappearance of mystery.

We can only hope in a single volume devoted to such a large subject as the foundations of the universe, to show the reader the main portions of the structure. If we liken it to a tree we can consider only the main stem and the larger branches. From these branches we may glimpse some of the larger twigs, but all the many ramifications cannot even be suggested. Perhaps the reader's imagination will contribute considerably to the picture of the more complete tree. We will concern ourselves primarily with such physical aspects as matter, mass, energy, and forces. These may appear prosaic and uninteresting, but their mechanisms, their relations, and their revelations are exceedingly interesting. The methods of the physicist are often picturesque. The experiments reveal really wonderful hidden processes. The relationships are often surprising and the contributions of these toward a picture of a unified universe are nothing less than marvelous. The harmony of the whole universe from atoms to stars, which knowledge is constructing, is beautiful — yes, that is the proper word — beautiful. Any failure to fascinate the reader will be due to the inability of the author primarily, and perhaps of the reader secondarily, to comprehend through mere human powers, the wonderful structure of an infinite universe.

Mere human beings, insignificant and of no influence or consequence, we find ourselves with our familiar dimensions midway in a universe of magnitudes almost infinitely large and small. The constituents of the atom are only a millionth the size of the smallest object that our unaided eyes can see. Most of the bodies of the stellar universe that are visible to us are billions of times larger and most of their distances are billions of times greater than the dimensions with which we

are usually concerned. Well may we wonder that man attempts to unveil the mechanism of the physical universe. Here we must thank our egoism, for, where it sometimes handicaps us, it is responsible for the incentive which makes us desire to know all that we can of the world of which we are apart rather than a part.

"So man, who here seems principal alone,
Perhaps acts second to some sphere unknown,
Touches some wheel, or verges to some goal;
'Tis but a part we see, and not a whole."

Pope

Chapter II

MATTER AND MOTION

If we contemplate for a few moments the portion of the physical world before us we conclude that it is made up of *matter* and *space*. As the moments pass by, one event following another leads us to the conception of another factor—*time*. It is obvious that motion involves space and time; that is, the displacement from one portion in space to another requires a certain amount of time and the whole process is termed *motion*. For a period in scientific development it was thought that all physical phenomena might be explained eventually in terms of matter, space and time. That is, there was hope for a single law which would explain all the physical things, events, and relationships in terms of movements of matter. But as scientific data accumulated, such a simplification became hopeless. In other words, a purely materialistic view could not account for the force of gravitation, for example.

Let us give some consideration to the apparently uninteresting fundamental which we term *matter*. At least it is important and is certainly the very foundation of the universe. Without it we would have only space and time which are not material. In fact, *we* would not have them for we would not exist. The physical universe as we know it would reduce to nothingness.

All matter has *weight*, that is, a certain degree of heaviness. In our infancy we become familiar with weight so that by the time we reach an age of reason we accept this as a fundamental of all things. Owing to the commonplaceness of the

phenomenon of *weight,* only an unsually observing and thoughtful person would even suspect that there might be a reason for it. Certainly in the centuries when there were relatively few accurate and correlated data of the physical world, we could not expect mankind to see much in common among a number of phenomena such as the weight of the body, the tides, a swinging pendulum, running water, the falling of an apple, the rotundity of the earth, the motion of the moon, the movements of planets and comets. But all these and many more movements of matter are bound together by law and a common property.

The Earth's Attraction

As we see a "strong man" lifting a heavy weight we do not visualize a pulling contest between him and the Earth. Nevertheless, that is just what takes place. As we climb a mountain we are in a competition with the Earth. Our muscles ache under the strain of overcoming the Earth's pull upon us. We dislodge rocks and they go rolling downward. We see nothing remarkable in that because they always roll downward. We would be surprised, indeed, it would be marvelous, if they rolled upward. But, after all, it is just as wonderful that they roll downward as upward. The difference is that in the one case it is natural; in the other it is unnatural. This exemplifies the confidence we have in the orderliness of Nature. In fact, the very basis of scientific inquiry and argument is the assumption that there is a reason for any given event of the physical world and that it is always the same for the same fundamental event. In other words, the assumption is that Nature is orderly and is always so; that is, that there are no exceptions, no miracles. We cannot prove that yonder object is heavy until we lift it. We cannot prove that the Sun

will rise tomorrow, but we are confident enough for all practical purposes because of our faith in the orderliness of Nature.

Perhaps the foregoing has served the purpose of emphasizing how we take for granted what in our experience has always been. Are most persons today any less indifferent toward what is natural or commonplace than those of any earlier time even in the primitive eras of little knowledge of the physical world? Of course, many persons now have had the advantage of some study of physics at least. But if we will visualize earlier centuries when science had not progressed far or even with much certainty, we can, perhaps, appreciate more fully the men who first began to inquire why things sought a lower level.

Galileo

Galileo saw a chandelier swinging gently to and fro and he wondered why. Thousands had witnessed the same thing since the beginning of man, but few contemplated the phenomenon thoughtfully, as he did. Apples had dropped for ages, but Newton (if the apple story is true) was one of the relatively few to wonder why. Primitive men learned early in their lives that some things were heavy and other things were lighter. This downward force, which we term *gravitation,* was utilized in many ways even by early races. There is nothing spectacular in the force of gravity. Being commonplace and universal in man's experience there is little wonder that it did not interest or was not even recognized by many persons as a great fundamental natural property of the Earth and of matter. So much more credit is due to those who did give their attention to it.

These discussions do not aim at historical treatment so no attempt will be made to go back to the first person who de-

voted study to this or that phase of physical science. In fact, it would be impossible in most cases to find a record of the first person. However, as a matter of interest and as an aid in presenting the various subjects somewhat in perspective, some of the early contributors of noteworthy data and analyses will usually be included.

Galileo (1564–1642) was born on the day of Michelangelo's death. One might fancy that this signified the passing of the sceptre from art to science, for science was destined to receive a great impetus from this remarkable man. While still a youth he discovered the regularity of the vibration of a pendulum by observing the swinging of the cathedral lamp of Pisa. He set to work and found that the vibration of a pendulum varies as the square root of its length. He recognized the utility of the pendulum as a timing device, but it remained for Huygens (1673) and others to perfect its use in clocks.

Shortly after his first observations of the pendulum, Galileo conducted his famous experiments on falling bodies dropped from the leaning tower of Pisa. By showing that the velocity of descent was independent of weight, he upset the idea which had prevailed for centuries that the velocity was proportional to weight. Many who saw his objects of unequal weights, dropped simultaneously from the same height, strike the ground at the same time, still did not believe that Aristotle (384–322 B. C.) and his followers were in error. When we contemplate that civilization had been progressing for many thousand years, it is difficult to believe that only 400 years ago Galileo was for the first time proving before an audience, which for a time was still to remain skeptical, the law of falling bodies. To us this is a simple law, but Galileo, in proving by experiment and placing in proper mathematical relation to other factors the acceleration of a falling body, made a con-

tribution to physical science comparable to all the work of the philosophers who preceded him.

He also studied the motion of projectiles under the two forces, the projecting force and that of the earth's attraction. Then Galileo turned his attention more to the heavenly bodies. Learning of the telescope invented in Holland, he constructed one for himself and began a series of noteworthy observations. He discovered the sun-spots, the satellites of Jupiter, the rings of Saturn, and the mountains and other markings of the Moon. What fascination there must have been to gaze upon these marvels that had been hidden from man's eyes for so long!

The Copernican Theory

Copernicus (1473–1563) developed the theory of circular planetary motions around the sun. When Copernicus was 19 years of age Columbus re-discovered America (for it had been visited by the Norsemen many years before). This lent proof of the rotundity of the Earth which was not fully proved "by experiment" until Magellan made his great circumnavigation. Shortly after this event, Tycho Brahe (1546–1601) was born of a noble Danish family. He became the greatest astronomical observer up to that time. It is said that he never went into his observatory for his night's work without being attired in his best clothing. When asked why he wore his silks and ruffles he replied to the effect that as he gazed at those celestial bodies he felt that he was in the presence of his Maker. Indeed, he must have.

"One sun by day, by night ten thousand shine;
And light us deep into the Deity;
How boundless in magnificence and might."

Young

Kepler's Laws

The stage was well set for the appearance of Kepler (1571–1630) who had a life-long struggle against poverty and ill health. Although he did not inherit the silks and ruffles that fell to Tycho Brahe, he did inherit great riches in the astronomical observations of his more prosperous predecessor. Kepler took up the Copernican theory of circular planetary motions, but was unable to reconcile the assumptions of uniform circular motion with the observational data available. He gave up the idea of uniform motion and also began to experiment with other closed curves. Finally he discovered that Mars describes an ellipse around the Sun and that the Sun was in one focus of the ellipse. This led to other conclusions which are known as Kepler's three laws pertaining to the motions of the bodies of our solar system. They are,

1. The orbit of each planet is an ellipse, having the Sun in one of the foci.
2. The straight line joining a planet and the Sun describes equal areas in equal times.
3. The squares of the times of revolution of any two planets about the Sun are proportional to the cubes of their mean distances from the Sun.

It will be noted that the first two laws concern the motion of any one planet and the third gives a relation between the periods and distances of the various planets. The determination of any one distance in the solar system, therefore, makes it possible to determine all other distances, because the periods of revolution can easily be determined by observation. It has been stated by some authorities that in the entire history of astronomy only two other works, those of Copernicus and Newton, are of equal importance.

It is seen that in the earlier period of scientific development, astronomical observations were contributing much toward an understanding of the physical world. This was inevitable because these data were obtainable by direct observation. Much of our present knowledge of the electron, of radiation, and of atomic structure is obtained by indirect methods which naturally are the result of this period of greater knowledge. However, even now, observations of the stellar universe and of the phenomena taking place in stellar crucibles are contributing much toward the development of physical science.

The Newtonian Epoch

By this time considerable knowledge of the movements of matter was available. Galileo's work with the pendulum, with falling bodies, and with projectiles had established a number of facts. Kepler's laws of the movements of the planets were available. In fact, much data of matter and motion had accumulated and the time was ripe for a generalization. Coördination of various laws and phenomena was lacking. This situation is reached every so often in scientific development and opportunity awaits the genius capable of the great work to be done. When opportunity and genius meet a notable epoch is the result. Such a time awaited the coming of Newton (1642–1727) and he did not fail.

Newton's imagination conceived the idea of an essential deadness of matter; that is, that matter could not of itself change its state of motion or of rest. Something had to do this for matter. This fundamental characteristic of matter he termed *mass*. It is something which, according to Newton, does not change. Einstein's modern view, which seems to be well founded, shows that Newton's theory is correct only under specific conditions. However, it happens that these

specific conditions are the ones we are ordinarily concerned with so that Newton's theory is practicable for our everyday use.

If matter could not move itself or change its state of motion, something had to be "invented" to do this, because it is well known that matter falls, that stones roll down hill, that the tides ebb and flow. For this purpose Newton's imagination created *force*. It was purely an hypothesis because it is not observed. We only observe its result as a change in motion. His great achievement was a definition of force which explained the movements of falling bodies on the Earth as well as of celestial bodies such as the Moon and planets revolving about the Sun.

If force is responsible for the change of motion of a body, the rate of change which it produces must be a measure of it. After considering the problem from various viewpoints he finally defined the quantity of motion of a body as the product of its mass and its velocity. Therefore, the change in velocity of a body due to a certain force was greater for a body of small mass than for one of a larger mass. This is the first introduction of the idea of mass as a property of matter. It became established that mass could not be destroyed and that it was constant for a given body. If the body was broken into parts, the sum of the masses of the parts equalled the original mass.

If the mass of a body is constant a change in motion must be due solely to a change in velocity which is *acceleration* in the case of increased velocity. Newton's hypothesis of force is that it is equal to the mass times its acceleration. The weight of a body is really the force of the Earth's attraction and may be stated thus; *Weight* or *Force equals Mass times the gravitational constant g*. This may give an idea of the difference in the weight of a body at different distances from the

center of the Earth. Inasmuch as the Earth is flattened at the poles, a body at the north pole is somewhat nearer the center of the Earth than one at the equator. Hence, a body is heavier (it weighs more) at the pole than at the equator. In other words, the weight of a body is variable because the gravitational constant is variable, the mass being constant.

Newton's law of gravitation or of attraction between bodies is as follows;

The force of attraction between two bodies (masses) is proportional to the product of their masses divided by the square of the distance between them.

This law has been invaluable to all branches of physics throughout the atomic and stellar realms. By means of this law and his laws of motion many far-reaching conclusions in physical science have been reached. It is easily understood why the " weight " of an object varies for different locations in space. For example, an object on the surface of the Earth is approximately 4000 miles from the center of the Earth. Suppose it has such a mass that the mutual attraction is a force of 160 pounds; that is, the weight of the object, say a man, is 160 pounds. At a distance 4000 miles above the Earth's surface, the man would be twice as far from the Earth's center and, therefore, would weigh only 40 pounds. It will be recalled that the force of attraction varies inversely as the square of the distance. If the man were in space at the distance of the Moon (240,000 miles) and the Moon were as far away as possible so its influence was negligible, the man would weigh about two-thirds of an ounce.

Newton's laws of motion may appear rather obvious to us, nevertheless, they were wonderful conceptions. They are axioms which cannot be directly proved, but they fit data and experiences so well that they have been indirectly proved

(with limitations) almost to the satisfaction of us Earth-beings. These laws are as follows:

1. Any body persists in its state of rest or of *uniform* motion in a straight line, unless acted upon by an external force.
2. Rate of change of motion is proportional to the force applied and is in the direction of this force.
3. To every action there is always opposed an equal reaction.

These laws will be recognized as a part of that often uninteresting course of physics which most of us have had at some time or other. But the interest is largely a matter of viewpoint and lies within the individual. Here it is hoped that these laws will be looked upon in a different light — as a fundamental and vital part of a wonderful structure which to us is the physical world. We have no means for proving these laws any more than we can prove any fundamental. A great structure was satisfactorily built upon them so they were accepted as correct. We cannot prove that a body will continue moving forever along a straight line unless acted upon by other forces, because other forces always exist. The second law shows how a force can be measured because it is really the definition of a force. The third law indicates that if a force is applied to a body an equal force (exerted by the body) must be overcome. For example, the Earth is pulling just as hard on a body that we are holding in our hands as we are.

Let us look at one of the difficulties that confronted Newton in his labors to unify the motion of bodies by means of fundamental laws. The falling of an object to the Earth seems quite unrelated to the revolution of the Moon around the earth or the planets around the Sun. The falling object travels in a straight line; the Moon and the planets travel in closed curves — ellipses. Furthermore, the velocity of a falling object con-

tinually increases; the velocities of the Moon and planets are more nearly constant, only varying between reasonably small limits. Add to these differences, the fact that a "heavy" body falls from a given height in the same time as a "light" one (neglecting air resistance).

It has been seen that Newton propounded the law that the attractive force between two bodies was proportional to the product of their masses. That is, a stone was pulled by the Earth and the latter was also pulled by the stone. Suppose one stone had three times the mass of another. It would be pulled three times as hard by the Earth, but it would also have three times the resistance to the Earth's pulling force. This results in equal accelerations of the two stones when dropped from the same height. As a consequence they fall together about 16 feet the first second, 64 feet the next second, 144 feet the third second, and so on.

In order to explain why the Moon does not fall to the Earth due to the attraction of it, it was necessary to attribute to it a motion of its own. If the Moon and the Earth had no independent motion and no other forces, but their own gravitational forces were acting, they would be drawn toward each other. The Earth would move slightly toward the Moon, but the latter would move most of the way because of its lesser mass. In fact as the Earth proceeds on its elliptical path around the Sun, the Moon in revolving around the Earth pulls the Earth slightly to and fro so that the Earth's path is slightly wavy. From accurate measurements of these variations it is determined that the mass of the Earth is about eighty-one times that of the Moon. After Kepler established his laws and the elliptical orbits of the planets, the variations from true ellipses of the actual paths of the planets due to the mutual attractions of the planets, were subjected to close scrutiny by Newton. He found that the laws that he had formulated ac-

counted for most of these variations very well. This led him to the universality of the law of gravitation.

It should not be difficult to conceive of the Moon, the planets, and other celestial bodies having an independent motion. If a bullet could be projected from the Earth at a sufficient velocity it would not fall to the Earth. It would go on travelling in a curved path which finally would be the resultant of its independent motion and of the change in motion due to the Earth's gravitational force. It would then go on describing a closed orbit around the Earth. It loses none of its velocity due to resistance of the medium of space because as far as we know space is a void from a material viewpoint. The Earth's force of attraction is satisfied by continually changing the direction of the path of the new "bullet" satellite.

If one has not thought of these matters seriously it may be difficult at first to conceive the possibility of the Moon not falling to Earth. Remember the tendency of the Moon is to travel forever in a straight line unless acted on by other forces. The Earth's force is the only important external one for the Moon, owing to the proximity of the Earth compared with other bodies. Under the action of the Earth's attraction the Moon does not travel in a straight line, but is pulled all the time from its straight-line tendency. The resultant is a closed curve at each point of which the position of the Moon is the resultant of all the forces acting. We are used to forces dissipating. We do not hope for perpetual motion in our mechanisms, because we cannot get rid of friction. A heavenly body is a mechanism of perpetual motion because, as it travels through the nothingness of space, there is no friction and therefore no loss of its own momentum in that respect. Apparently there are similar mechanisms within the atom.

Limitations of Newton's Laws

Newton's laws of motion and gravitation are epochal because they are really the foundation of dynamics. They were amply verified throughout many years and were the basis of physics for two centuries. As already stated they are still acceptable for all practical purposes of the Earth-being, but being based upon absolute space, time, and matter they are shown to be only special cases of Einstein's wonderful conception of the cosmos which is discussed later. Einstein, who can be credited with one of the greatest achievements of human thought, has said, "Newton's theory is probably the greatest stride ever made in the effort toward the causal nexus of natural phenomena." These laws explained observed data and predicted phenomena very well for all practical purposes and for most scientific ones. But certain observations in astronomy were not quite satisfied by them. In new physics, some phenomena connected with rapidly moving small particles and with light and radiation were not accounted for by the Newtonian laws. As has been stated, this assumption of absolute time, space and matter satisfied the Earth-being in his everyday affairs and also if his observations did not extend too carefully into the stellar and atomic worlds.

Einstein became dissatisfied with certain inconsistencies that had arisen between theoretical physics and observed data. He began with the premise that time was not absolute; that is, that statements of time depend upon the viewpoint of the observer and that two observers moving with respect to each other would differ in their statement of time. Einstein built up a principle in which space, time and matter are relative, hence, the principle of *relativity*. This was destined to revolutionize scientific thought. The velocity of

light now plays in physics what infinity does in mathematics. Statements of time must satisfy the demand that the velocity of light is invariable in all directions. Mass varies with the velocity of the body, becoming infinite at the velocity of light. When a mass becomes infinite a force acting on it cannot alter its velocity, therefore, the velocity of light is the highest attainable. Mass becomes associated directly with all energy, and energy with all mass. The failure of Newton's laws is chiefly noticeable when dealing with velocities approaching that of light.

Mankind could have gone on developing science without serious handicaps by the use of Newton's laws; however, it appears that never would the whole scheme of the cosmos have been revealed in its simplest form without the new Einstein concepts. The chief drawback of the principle of relativity, is that it cannot be visualized by minds of the three-dimensional world. Space is of three dimensions. Time being relative instead of absolute, we must consider it as well as the three dimensions of space. This is easy in mathematics, but a four-dimensional world cannot be conjured up in the mind's eye. Nevertheless, this far-reaching principle, which has so far passed with flying colors tests that have been applied, is treated briefly in a later chapter. In the meantime, let us be assured that Newton's laws can be safely depended upon for most practical and scientific purposes.

Chapter III

MOLECULAR MOTION

Perhaps to a primitive mind the earth consists of stones, grains of sand, dust particles, drops of water, and similar things. In other words, it is made up of parts. One cannot contemplate Nature for long without noting that disintegration and transformation are continually going on. Ice melts to water; the water vaporizes; the vapor condenses again to water; it freezes to ice. Clouds dissipate themselves in rain or snow. Rock disintegrates into sand; the sand into dust; the dust is carried away by wind and water. Thus, visible things become invisible and the invisible may become visible.

It is not surprising that Anaxagoras (500–428 B. C.) propounded the principle that the material of Nature was compounded of and could be resolved into elementary *seeds* of matter. This idea found advocates throughout the ages, although it was little more than a speculation in early centuries. Leucippus believed that the universe consisted of limitless empty space and of matter, the latter consisting of numberless, indivisible atoms. He also thought that atoms were always in motion. As usual, there were many fantastic ideas interwoven in these speculations.

Democritus (460–370 B. C.), a pupil of Leucippus, developed the theories of his teacher to such an extent that generally his name is the only one associated with these early speculations of empty space and atoms as elements of the cosmos. He also developed the idea that all the material of

the universe was produced by the motions of these atoms. He was an extreme sceptic as indicated by the remark attributed to him,

"We know nothing; not even if there is anything to know."

Although many of his speculations can be very easily modified to fit the facts of the physical world as we know it today, he contributed little of real note to science excepting an example of the value of a critical attitude. Nevertheless, the idea of atomism had to have a beginning and it matters not if it began in metaphysics and alchemy. It has eventually arrived a definite reality. It aided in the development of chemistry which in turn developed atomism. Spectroscopy did much to place the atomic theory of matter on a firm foundation. Finally radio-activity, that marvelous exhibition of the birth of one element from another, has made us even better acquainted with the atom.

In the development of the atomic theory of matter, the foundational laws of the great stellar world were applied to the tiny worlds far beyond the revealing power of the microscope. The great laws which were developed to explain the motions of the Moon, planets, and other celestial bodies and were so clarified by Newton, soon began to serve to explain the structure and properties of matter and eventually of atoms themselves. Motions and masses were attributed to minute molecules, atoms, and electrons with the result that the energy of motion of these small particles became a very important factor in explaining various physical phenomena. Hence, the introduction of the term, *kinetic energy*. As will be shown later, modern developments impose limitations upon the applications of Newtonian mechanics, but for the present we need not consider them in detail.

Kinetic Theory of Heat

The atomistic idea has not been limited to the structure of matter by any means. It is associated with several properties or characteristics of matter such as heat, gas-pressure, and light or radiant energy. The early idea of heat was that it was a fluid. Count Rumford (1753–1814) a little more than a century ago was one of the first to relegate this idea to the discard by experiments which suggested that heat was a mode of molecular motion. It is true that Roger Bacon (1214–1294) suggested heat was a matter of agitated particles such as molecules, but as in other phases of science, experimental data were lacking. Mayer and Joule (1842) discovered that mechanical work was converted into heat and that the amount of heat was always exactly proportional to the amount of work and *vice versa*.

It had long been recognized as a direct consequence of Newton's laws of motion, that energy could not be destroyed. This is the well established law of conservation of energy. For example, if a moving body collided with another body, the resultant mechanical energy remained equal to the total before the collision. The total mechanical energy required to produce a certain amount of heat (agitation of the molecules of the body in which the heat was generated) would remain unaltered. The molecules of the body now possessed so much more mechanical energy; in other words, they were sufficiently more agitated so that their excess mechanical energy was just equal to the mechanical energy required to produce the amount of heat that the body received.

Thus we see not only the atomistic idea of matter used to account for a change in temperature (due to the production of a certain quantity of heat), but also Newton's laws of motion applied to the molecules of the body. It is a beautiful

picture of unification. For example, suppose a large iron ball is dropped from a height and it strikes a thick iron plate of great mass. The mechanical energy of the falling ball at the moment before striking the plate is proportional to its mass and the square of its velocity. Actually the ball will bounce a few times, but let us assume it always hits in the same place and comes to rest there. The energy of the ball is now distributed among myriads of molecules of iron both in the plate and in the ball. Owing to the minuteness of the agitated molecules we cannot see their increased movements, but we can feel the result of the increase. The two bodies are of a higher temperature at first only near the points of contact, but the heating effect rapidly spreads and equalizes. This is what we term *conduction of heat* and is really a communication of the increased agitation to other molecules. It should be noted that the molecules of a body are always in a state of agitation (excepting at absolute zero), the degree of agitation being indicated by the temperature.

Kinetic Theory of Gases

The atomistic principle rendered a very great service in the development of a picture of gases which could account for such properties as pressure. Newton's mechanics, which contributed so much toward our knowledge of the stellar universe, finds a beautiful application to the molecules of a gas. Although the conception of the idea of the kinetic theory of gases can be traced further back, Clausius (1857) really founded it after Joule (1851) had attempted to calculate the velocity of a hydrogen molecule. The calculations were inexact, but they mark the beginning of an actual atomic view of matter as distinguished from the mere symbolic view of the chemist up to that time.

The molecules of a solid are considered to be bound to certain positions which result in equilibrium, but this is not the case in gases. The molecules of a gas are continually in motion, excepting at *absolute zero,* about 491 degrees Fahrenheit below the melting-point of ice. At first they were likened to elastic spheres shooting in all directions and colliding with each other. At ordinary temperatures and pressures a gas-molecule will suffer several billion collisions each second. Although the modern ideas of the atom are not fully developed in relation to the kinetic theory of gases, it is likely that the molecules do not actually collide in the ordinary sense. The modern conception is that atoms are tiny planetary systems of electrons revolving around a positive nucleus. Doubtless they are surrounded by electric forces so that instead of a collision we have a repulsion of the electric forces. At any rate the true picture is of little consequence here because it will not alter the actual facts.

The pressure on the sides of a vessel containing a gas is due to the billions of collisions of the molecules with the sides. The force of an impact is determined by the mass and the velocity. The pressure is the result of the number of impacts per second. If the density of the gas is doubled there will be twice as many impacts in a second on a given area of the vessel and, therefore, the pressure will be doubled. This relation of density and number of molecules was suggested by Boyle (1627–1691) which gave rise to *Boyle's law.* This law states that, for a given temperature, the product of the pressure and the volume is constant.

The temperature of a gas is determined by the mean energy of motion of a molecule. Here again Newton's mechanics enter, for the energy of motion of a molecule is proportional to its mass and to the square of its velocity. As the temperature decreases, the energy of motion (kinetic energy) of a molecule

decreases until at absolute zero there is no motion. Hence, at absolute zero the pressure of any gas is zero. It may be of interest to know that absolute zero has not quite been reached in the laboratory, but it has been approached to within less than a degree Centigrade.

Size and Number of Molecules

It is interesting to view the particles of gas more intimately. The velocity of a molecule of gas depends upon its mass. At the temperature of melting ice, hydrogen molecules have an average velocity of about one mile per second. Oxygen molecules being about sixteen times heavier travel about one fourth as fast as hydrogen molecules. These velocities are of the order of magnitude of projectiles fired from guns. It is fascinating to think of the nitrogen and oxygen molecules of the air about us moving between collisions with the velocities of bullets. They are striking our faces with these velocities and it is obvious that we should be thankful for their very small mechanical energy. We cannot conceive the smallness of the mass of a hydrogen molecule. Its mass is related to that of a baseball about as the mass of the baseball is to that of the Earth. There are about 10^{25} molecules of hydrogen per ounce of the gas, or 10 million billion billion molecules or 10 trillion trillion molecules per ounce. The reader may take his choice of these numbers, but it is likely that the baseball comparison of relative mass gives a better idea of the size than the foregoing numbers. The diameter of the hydrogen molecule is less than ten billionths of an inch (8.5×10^{-9} inch). Particles must be a thousand times larger to be visible under the most powerful microscope. (See Fig. 2.)

Perhaps some idea of the number of molecules in an ounce of hydrogen gas might be obtained if we set out to count them.

There are about two billion persons on Earth. Suppose each was able to count 100 molecules per minute continuously. It would take the entire population of the Earth one hundred million years to count the molecules in an ounce of hydrogen

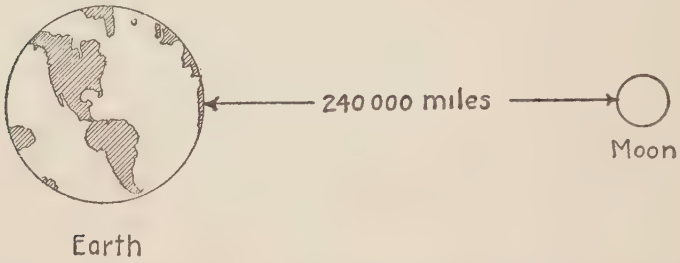


FIG. 1. If all the molecules in a cubic centimeter (one sixteenth of a cubic inch) of hydrogen gas at ordinary temperature and pressure, were placed end to end in a single line, this "string of molecular beads" would extend several million miles or many times the distance between the Earth and the Moon. In a cubic centimeter of hydrogen at atmospheric pressure and at the temperature of melting ice there are 2.7×10^{19} molecules, each having a diameter of 2.17×10^{-8} centimeters. Less than a millionth of the total space is occupied by the hydrogen molecules under these conditions.

gas. The mass of the Earth is again inconceivably greater than the mass of hydrogen weighing an ounce at the Earth's surface, so it is seen that the number of molecules in the Earth alone is quite beyond comprehension. Similarly the greatest known distances in the stellar universe are inconceivably large. The human being is puny indeed and his mind can never comprehend the picture in its entirety. Nevertheless, we may enjoy knowing that there will always be awesome magnitudes to contemplate when we desire to exercise our imagination. There would be a maximum of about 7 billion molecules in a single row of them five feet long and it would take a person a lifetime to count the number in this short row of molecules in "single file." (See Fig. 2.)

The Statistical Method

In dealing with molecules and other minute particles of matter which are shooting about as in the case of a gas confined in a vessel, we cannot arrive at any definite conclusion without studying averages. A single molecule, if we take

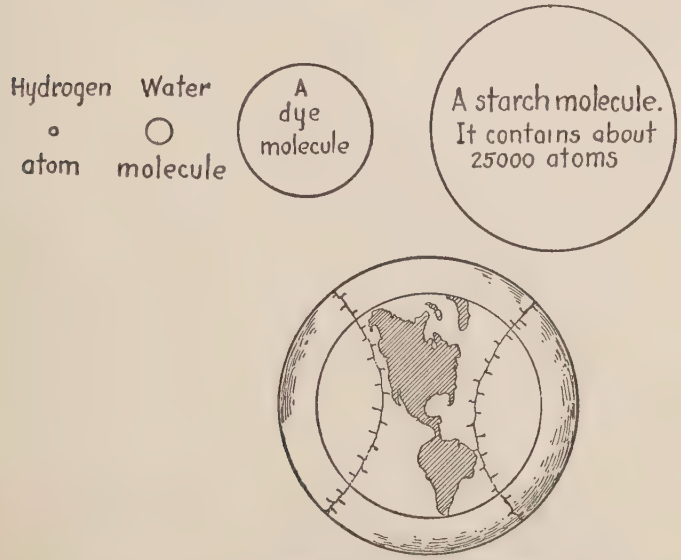


FIG. 2. Showing the relative diameters of the hydrogen atom and three molecules of substances, namely, water, a complex dye, and starch. These relative sizes are represented by circles, but the molecules may not be spherical. An electron is probably less than a hundred-thousandth the diameter of a hydrogen atom. The diameter of the hydrogen atom is only a few billionths of an inch. If the relative size of a baseball were shown on the same scale it would be larger than the Earth by the amount indicated above.

averages, collides billions of times per second. If we direct our mind's eye upon any one molecule of a gas, we will find that its path is hapazard, unpredictable, and quite accidental. The same is true of the course of life of any human being. However, the insurance companies by observing a large number of

persons can make sufficiently accurate predictions upon which to base a sound business. Anyone of us may die the next moment, or fall out of a window tomorrow, or collide with a street-car the next day. When an individual will marry, how many children he will have, or how much money he will acquire, only the future can tell us. No one can predict what will happen in a particular case, but from adequate records of a sufficient number of cases a safe prediction can be made based upon the "law of averages." Many applications daily are now made of the results of statistics and science has successfully utilized the statistical method in various ways.

Maxwell (1841–1879) was the next great mathematical physicist after Newton to greatly change the course of scientific thought. Although he has greater scientific achievements to his credit, he placed the kinetic theory of gases on a firm foundation from which it has not been shaken, by developing the statistical method. He applied natural laws to the individual molecules, but without attempting to follow an individual he gave his attention to *totality*. It has been seen that the number of molecules in even a small quantity of matter is very great; therefore, we can have faith in the law of averages.

It is certain that the movements of molecules of a gas depend upon less complicated factors than the lives and activities of human beings. All molecules of the same element or gas have equal masses, with slight exceptions of no consequence at this time. The kinetic energy of any one is determined by its mass and velocity. The mean velocity of the molecule, based upon the study of the combined effect of the billions of molecules, is a very definite and constant value for any given set of conditions. In fact, about all we must convince ourselves of in order to have faith in the statistical method as applied to gases, is that the rate of collision of molecules is constant for a given pressure, volume, temperature and gas.

Perhaps it will aid the reader to have faith if we revert momentarily to the number of molecules. A minute sphere two thousandths of an inch in diameter is about as small an object as we can see with the unaided eye at a distance of one foot. If this sphere were filled with gas at atmospheric pressure and of ordinary temperature, it would contain about 2000 billion molecules. Expressed in another way this number is equivalent to two million million. Counting at the rate of 100 per minute for the usual working hours throughout a year, it takes a person a lifetime to count a billion. At this rate it would take 2000 persons their entire lifetime to count the molecules in that minute sphere two thousandths of an inch in diameter. Insurance can be safely based on the statistics of a number of persons, relatively few compared with the number of molecules in a sphere invisible to the unaided eye. Considering this fact along with the more complex vagaries of human beings as compared with those of molecules, it is seen that we can have utmost faith in the constancy of the results of the statisical method as applied to molecules of matter. Maxwell established these facts beyond question.

Brownian Movements

If we suspend in air an object easily visible to the unaided eye, it will be subjected to collisions from all directions, of molecules of the gases in the atmosphere. But we do not see it move here and there because it is being bumped from all directions. The number of molecules colliding with it per second is inconceivably large. Even in the smallest part of a second necessary for our consciousness to note a movement of this small suspended object, it would receive billions of impacts. The force upon it would be equal in all directions owing to the application of the law of averages so that even if it had no mass, it would not be moved appreciably.

However, if we reduce the size of this suspended object, we should be able to arrive at a point where there is not a sufficient number of collisions from all directions for the effect to be equalized on all sides. In other words, the particle would be subjected to different forces from various sides and we would expect it to be bumped here and there in a haphazard fashion. Brown (1773–1858), a botanist, while examining under a microscope some liquids containing particles of pollen about one thousandth of an inch in diameter, noticed that these particles moved irregularly. He also noticed that the movements were more conspicuous for the smaller particles. Brown did not explain this, but, scientist that he was, he recorded his keen observations.

With the establishment of any new principles and generalizations which are shown to be sound, many of the observed facts of past records are explained. Brown's observations were to await the kinetic theory of matter before true light could be shed upon them. Hence, about fifty years later the Brownian movements were shown to be due to the impacts of molecules of the liquid in which the pollen particles were suspended. The same kind of movements have since been demonstrated in gases. It has been shown that fine particles of matter, such as gamboge suspended in water, obey the same laws that have been applied successfully to molecules. Some of this work has provided experimental foundation for the theory that the average energy of motion of the particles or molecules of a mass of matter depends only upon the temperature of the matter and not upon the mass of the particles. It was also shown that these particles, although very much larger than molecules, had an average energy of *rotation* equal to their average energy of *translation*. This also added support to the prevalent theory.

It is seen that the study of Brownian movements contributed much toward the establishment of the kinetic theory of matter.

States of Matter

Having accepted atomism, it is necessary to account for the differences between solid, liquid, and gaseous states. Matter in any of these states consists of molecules. Ice, water, and steam represent three states of the same compound of hydrogen and oxygen. Mercury, an element not a compound, can be solid, liquid, or gaseous. Usually a solid passes through a liquid state before becoming gaseous: however, it is possible, at certain temperatures and pressures, for solids to pass directly to the gaseous state or from gas to solid.

It has been seen that the result of heating a body (increase in temperature) is to increase the energy of motion (kinetic energy) of the molecules of which it consists. In the solid state the molecules are thought to be bound together by certain forces so that we have a condition of stability and, to a degree, orderly and permanent arrangement. For the present we need not be concerned with the details of shape and arrangement of the molecules. Perhaps it is sufficient to imagine a box full of egg-shaped rubber balls bound together by thin rubber bands. If the balls are hollow and contain a mechanism which will make them vibrate, we will have a vibrating mass, the individuals of which are limited in their movements. If the effect of the internal mechanisms could be controlled so that the agitation could be varied, we would be able to demonstrate in a crude manner the " solid " at various temperatures.

When the temperature was increased to the proper value, the elastic bands would break and the individuals would be freed. They would then begin to bounce and collide haphazardly and would try to escape from the room. This would be a crude picture of a gas.

A crystal could be pictured the same as any other solid, but the molecules would be arranged in a more orderly manner.

If a room contains many elastic balls bouncing here and there, we have a picture of a gas. Suppose that a layer or two settles to the floor, but still is in an agitated state. This may be considered a crude model of a liquid above which is its vapor.

By rubbing two solids together their temperature is increased by an amount equal to the work done in overcoming friction. It may be considered that the molecules in the surface layers have been excited into more violent movement resulting in greater average kinetic energy, hence, in higher temperature.

Absolute zero is that lowest possible temperature at which the molecules of matter cease to vibrate. This logically follows from the kinetic theory of heat and of matter. Absolute zero is at about 459° F. below the ordinary Fahrenheit zero or 491° F. below the freezing point of water. On the Centigrade scale it is about 273° C. below the Centigrade zero which is at the freezing point of water.

It is well known that a liquid is cooled by evaporation. If we consider that a liquid consists of molecules moving haphazardly (within certain limits) due to collisions with each other, some of these molecules will have sufficient speed to escape the attractions of their neighbors. These, then, find themselves in the space above the liquid and are now a part of the vapor above the liquid. Inasmuch as the only molecules which escape are those having a great enough velocity in a direction away from the surface of the liquid, it is obvious that the liquid is losing only those molecules which at the time of escape have much more than average kinetic energy. Such losses result in a lower average velocity of the molecules left in the liquid and therefore the temperature of the liquid decreases.

Inasmuch as the molecules of matter do not cease to vibrate or to move about until absolute zero is reached, it is obvious

that there is much kinetic energy in bodies at ordinary temperatures. A piece of ice is *cold* to us, but it is relatively *hot* compared with liquid air and even more so compared with absolute zero. Here we must eliminate our sense of temperature and look at Nature without this prejudice. There is enough total kinetic molecular energy in a piece of ice the size of a baseball to raise a ton weight more than 30 feet vertically. If we could find a means of extracting the total kinetic energy of the molecules of a piece of ice of this size each second, we would have the equivalent of a motor of about two horse-power. It should be noted that the foregoing involves only molecular energy and not so-called chemical and atomic energy.

Other Applications of Atomism

The great success of the atomistic principle as it is involved in the kinetic theory of matter is one of the wonders of the modern scientific age. It is to be expected that it has found other applications equally fascinating and promising. It is now being pressed further into the service of explaining the structure of matter. Molecules are not only divided into atoms, but the latter are now known to consist of still smaller particles. The reality of the electron is thoroughly established. It takes 1800 electrons to equal in mass that of an atom of hydrogen which has the smallest mass among the atoms of elements.

When Maxwell (1873) propounded the electromagnetic theory of light (radiation), his achievement was epochal. The exact manner in which the radiant energy traversed space was not known, and the next epochal event was the founding by Planck (1900) of the *quantum theory*. Here we have the atomistic principle applied to energy instead of being confined to the *material* of the universe as it had been. In other words, in the quantum theory we have the atomistic idea applied to

physical *processes*. We now have the atom of matter, the atom (electron) of electricity, and the atom (quantum) of action (a product of energy and time). Planck assumed the emission of radiation (from the sun, a lamp filament, etc.) to occur discontinuously. He conceived elements of energy of equal magnitude analogous to the equality of electrons, or atoms of a given element. Radiation or radiant energy is emitted of various wavelengths or frequencies which must be taken into account in laws of radiation. By inventing the *quantum of action* Planck was able to derive a law of radiation which explained the experimental data hitherto not understood. The elementary quantum of action is equal to the elementary quantum of energy multiplied by the frequency of the radiation. Thus again, we find science in a state which required a creative mathematical physicist to iron out inconsistencies, to put the finishing touches on existing theories, and to explain much of the accumulated data.

Now the physicist uses *quanta* as commonly as he does electrons and atoms and molecules. Bodies are built of molecules, the molecules of atoms, and the atoms of electrons (and protons). Here we see the atomistic principle applied to "material" (matter) and then to electricity (What shall we call it?). Finally, a physical process — the radiation emitted by the electrons — is divided into *quanta*. With such pictures of the universe being constructed we may cease to be surprised at anything, but our interest and admiration will grow. Will we ever get to the final foundation? Will mind be finally explained by the physicist?

These are mere glimpses of the electron theory and the quantum theory introduced to complete this portion of the picture for the present. They are so important, so modern, and so far-reaching that they are treated later in more detail.

CHAPTER IV

THE NATURE OF LIGHT

One of the most marvelous relationships that has ever been revealed in the entire science of physics is that between light and electricity. Knowing what we do at the present time in regard to the structure of atoms, this relationship is not quite so surprising. However, considering the total absence of knowledge, a half century ago, pertaining to the existence of electrons in atoms of matter, the sudden revelation that light (and radiation in general) was an electrical phenomena was very startling and revolutionary. Even today those persons who are unfamiliar with fundamental physics find it difficult to believe that energy traveling from yonder star to the eyes is electromagnetic in nature. But that it is so has been amply proved. The atoms in those distant stellar crucibles have moving electrons which are emitting electromagnetic waves of many wavelengths or frequencies. Here on Earth we have many " receiving stations " which are tuned to certain ranges of wavelengths.

Light and Radiation

Our eyes respond to those frequencies which we loosely term *light*. The photographic plate records these and also invisible radiations of shorter wavelengths (higher frequencies) known as *ultraviolet radiation.* There are also radiations of longer wavelengths (lower frequencies) which are termed *infra-red radiations.* These are generally measured by their heating effect. There are electromagnetic radiations of still greater

wavelengths, some of which are termed *electric waves*. Some of these are used in wireless telegraphy and radio. There are also electromagnetic radiations of very short wavelengths known as *Röntgen radiation* (X-rays) after their discoverer; and also radiations of still shorter wavelengths emitted by radium which are termed *gamma radiation*. Sometimes the term *light* is used by extension to include the whole gamut of radiations. It seems best to restrict the term *light* to the visual sensation due to certain radiations, but inasmuch as the term has been used to cover the entire range it will be so used here. However, when it is necessary to make a definite distinction, particularly in regard to wavelength, this will be done. Therefore, in what follows the word *light* will be used in various ways.

Early Knowledge of Light

Until the beginning of the nineteenth century invisible radiations had not been discovered; therefore, up to that time light meant visible radiation. Certain laws of optics, such as reflection and refraction, were well known for many centuries. It also had been recognized that light traveled in straight lines from the source unless diverted by reflection from opaque objects or by refraction in transparent media. During the seventeenth century diffraction of light, double refraction by certain crystals, scattering of light by fine particles, and colors of thin films, had been discovered, studied and more or less accounted for. It had been established that light travels with a definite finite velocity which is constant for a given medium. Newton (1643–1727) directed his great genius to the study of light and, as is well known, he accounted for the colors of the spectrum, partially at least, by the different refrangibilities of radiations of different wavelength. He propounded an emission-theory of light which in some ways may be considered as laying the

foundation of the present accepted theory. He regarded light as a substance of very fine particles emitted by the source.

Huygens (1629–1695) developed the undulatory or wave-theory of light which was generally accepted a century later. He considered light to be of the nature of mechanical waves, but this required the invention of a substance for transmitting these mechanical waves through otherwise empty space. As a consequence the hypothetical *ether* was introduced to the world and this "invention" was destined to receive much attention and to cause much controversy. Recent developments in science seem to indicate that the *ether* may be destined to disappear through lack of necessity for even an hypothetical existence.

Newton made a great and lasting contribution when he discovered the periodicity of light; that is, that it consisted of waves, although he made no attempt to develop an hypothesis regarding them. Oddly enough his contemporary took up the idea of waves and propounded the undulatory theory of light. Owing to the powerful influence of Newton the wave-theory did not win favor in competition with Newton's emission-theory. However, like in all cases, truth survives, so that Huygens eventually received his just dues by the general acceptance of his theory a century later. But, as is often the case, there was something of merit in both theories and something that had to be revised. The wave-theory has survived, but the idea of mechanical waves had to be discarded. Something of the nature of Newton's emission-theory has been combined with the wave-theory in the accepted theory of radiation of the present time.

Light-Waves

One important idea these men held in common. They agreed that light is a *periodic process in time and in space.* Frequency

is periodicity in time. It represents how often a certain event or cycle is repeated per second. If this wave-motion is projected or propagated into space as light is, we may measure the condition between two points in space at the same time. This gives the periodicity in space. Suppose we tie one end of a rope to a post and hold on to the other end with the rope stretched taut. If we shake our end of the rope up and down, a series of waves travels along the rope. The periodicity of our end of the rope is the frequency. The number of waves along a given length is the periodicity in space. The wave-length is the distance from one crest of a wave to the next one. The distance traveled by a wave in a given time, such as a second, is the velocity. A crude model of light-waves can be made in our imagination if we consider the series of waves just sent down the rope to be repeated with a great many ropes at the same time, but vibrating in as many different planes. If we could fix any series of waves of the rope and then rotate the whole length, by twisting our end in our hand, we could get an idea of the transverse waves of light.

Although the wave-theory of light gradually gained popularity over Newton's emission-theory, it had some serious difficulties. For example, other waves were generally observed to pass around objects to some extent; that is, they went around corners. However, sharp edges of objects were seen to cast sharp shadows. How could these sharp shadows be reconciled with a wave-theory of light? Obviously the first step toward success in any enterprise is to determine whether or not that which *seems* to be true *is* true. In astronomy it has been seen that Copernicus gave science a powerful impetus in the right direction by abandoning the idea that the earth was stationary even though the celestial bodies appeared to revolve around it. His great achievement was in refusing to accept what had been accepted.

In optics we had a similar situation at the beginning of the nineteenth century, but science in this field was not set aright so suddenly. Perhaps the hesitation and faltering progress was due largely to the powerful influence of Newton which continued long after his death. The wave-theory of Huygens not only was handicapped by certain inherent difficulties, but it had to compete with the influence of Newton which was on the side of an emission-theory. However, Young (1773–1879) boldly revived the wave-theory and accepted the idea of an elastic "luminiferous ether" pervading all space. He also supported the hypothesis that the colors of the spectrum were the result of different frequencies of light impinging upon the retina of the eye.

Then comes Fresnel (1788–1827) who proved to be to optics what Newton was to matter and its motion. He unified the conceptions of his predecessors into a wave-theory which was acceptable in that it explained certain phenomena such as "sharp" shadows. As a matter of fact, shadows are not sharp when closely examined. Light is diffracted. Along the edge of a shadow cast by a sharp edge is seen evidence of light traveling around a corner. Thus a common belief was exploded and it helped along a theory which was being handicapped by a false belief. It may be said that Fresnel established the wave or undulatory theory of light on a firm foundation, although the idea of mechanical waves in an hypothetical ether was still questioned. Not only was it difficult to believe that space, which was manifestly empty, contained something of certain properties, but transverse waves could not be reconciled with the theory of elasticity excepting in a solid medium. Sound waves are longitudinal; that is, the particles of the medium (air, for example) vibrate only in the direction the sound is traveling. If we hang a weight on a rubber band and bob it up and down, the rubber band will be stretched and

relatively relaxed alternately. This corresponds to a compression and a rarefaction which is a characteristic of longitudinal waves. However, it had been amply proved that light-waves were transverse so the theory of elasticity ran counter to the idea of an elastic ether. According to the prevailing ideas of elasticity *only* longitudinal waves could occur in the ether if it were fluid. They could only occur in a solid if the latter were incompressible. Transverse waves could only occur in a solid and, therefore, could occur without longitudinal waves *only* in an incompressible solid. Obviously it was difficult to believe that the hypothetical ether was an incompressible solid which did not offer resistance to celestial bodies. If it offered resistance to the movements of the planets, certainly they should slow down gradually and by this time the whole universe would have been stationary, piled up, destroyed or what not!

The Epochal Maxwell

We have seen the wave-theory of light gradually acquire a full-fledged acceptance. It was almost correct. It erred in the matter of mechanical waves in an hypothetical ether of properties which could not be reconciled with other theory, observation, and experience. Again the scientific world finds itself awaiting the mathemetical physicist and philosopher whose imagination can construct a new picture. A great opportunity for generalization awaited Maxwell (1831–1879) as had awaited Newton, and like Newton he did not fail. Science always offers opportunity, but only occasionally do sufficient facts accumulate and along with them inconsistencies due to inaccurate or incomplete theories, to offer the great opportunities. These are the epochal events of scientific progress. Lorentz and the electron theory, Planck and the quantum theory, Einstein and the theory of relativity are such events.

In the early part of the nineteenth century when Oersted (1777–1851) and Faraday (1791–1867) were unravelling the mysteries and electromagnetism no one dreamed that they were preparing for the nuptials of light and electricity. No one could have seen any relation between these two phenomena. *Electric currents* had already been discovered. Oersted discovered that there was a magnetic field in the vicinity of a conductor carrying an electric current. Faraday found that a current was generated in a conductor when it was passed through a magnetic field. In other words, when the magnetic field varies a current is induced in a closed conducting circuit which is located in that varying magnetic field. Electrical theory was built upon the data of *electromagnetism* and *induced currents*.

Maxwell extended some of these ideas further. He assumed that currents can exist in insulators and even in empty space. These he termed *displacement currents* and ascribed the same properties to them as had been observed for currents in closed conducting circuits. This hypothesis, arrived at by deductive philosophy, he introduced into the theory of electromagnetism. The result was marvelous. From his mathematical structure emerged the *theoretical possibility of electromagnetic waves*. These waves were transverse which fitted the known facts of light, and they were electromagnetic rather than mechanical. If light-waves could be proved to be electromagnetic waves, it is seen that some of the latent difficulties of the older wave-theory of light would disappear. Inasmuch as suspense is not one of the necessary ingredients of a book of this nature, the reader will be assured at this point that Maxwell's electromagnetic theory overcame many major obstacles with everlasting glory. The ether was still retained, but its properties were now somewhat different from the mechanical properties of solids as the wave-theory had

assumed previously. It cannot be said that the ether is fundamental in Maxwell's theory, but was retained more for the purpose of constructing a mechanical model of the theory. The laws themselves were definite, but the model was indefinite. It is well to note that the idea of action at a dis-

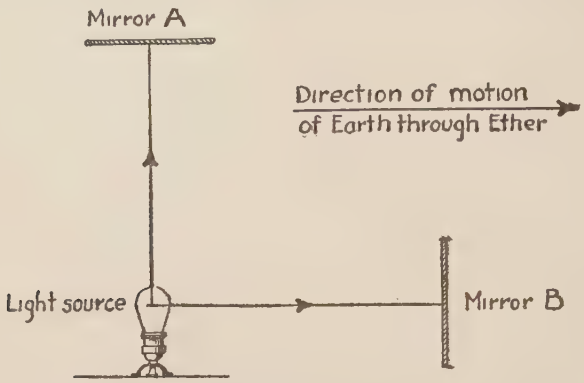


FIG. 3. The famous Michelson-Morley experiment in which no relative motion between the Earth and the ether was detected. The time required for light to travel from the light-source to and from mirror *A* was found to be the same required to travel an equal distance to and from mirror *B*. If there is an ether drift the latter time should be the greater.

tance is difficult to conceive without some medium in between. Here again we are handicapped by the prejudice of our inadequate senses and by our "materialism" which had something to do with the demand for an ether.

In the presentation of physical science to the general reader mathematical treatment is necessarily taboo. This places a great strain upon mere verbal treatment. Mathematics are short-cuts in representation and, furthermore, they represent very often phenomena or processes that cannot be described in words or pictured by models limited to three dimensions. In the foregoing, the events leading up to Maxwell's theory and the general nature of the theory have been presented

briefly. It is true that only a bare glimpse has been given of the electromagnetic theory of light and therefore the reader can gain from this only a faint conception of it. In any case, a complete discussion cannot be presented in a few pages and without mathematics. Perhaps a paragraph or two will aid those who desire a further glimpse.

Maxwell produced electromagnetic waves in theory, but how are they actually produced, if at all? It is well known that an electric field exists around an electrically charged body. This is not the familiar magnetic field, because that is quite another matter. We detect and measure the strength of the electric field by measuring the force of attraction or repulsion exerted on a so-called test-charge which we bring into the neighborhood of the charged body. This field strength has direction as indicated by the direction of the force it exercises on the test-charge. When the strength of this electric field varies at a given point periodically in magnitude or direction, electric oscillations take place at the point under consideration. It follows from Maxwell's theory of displacement currents that periodic changes in the electric field (in strength and in direction) give rise to periodicity in space or to an electric wave. The wave-motion is similar to that described earlier in this chapter. The same discussion may be applied to a magnetic field and magnetic waves result. In the Maxwell theory, electric waves are accompanied by magnetic waves and vice versa; and the electric-field strength is always perpendicular to the magnetic-field strength and both are perpendicular to the direction in which the waves are travelling. These ideas are natural sequences of the facts of electromagnetism.

In dealing with electric fields, it is obvious that we must have a unit of measure which is different from that used in dealing with magnetic fields. In other words, we have a

system of electrostatic units and one of electromagnetic units. For example, an electric current can be measured in terms of the strength of the magnetic field due to the flowing current or in terms of the quantity of electricity passing any cross-section of the conductor in a given time. The ratio of the unit of electric current for the two systems is not merely a *number* but a *velocity*. Weber (1804–1891) actually measured this ratio experimentally in 1856 and found it to be *equal to the velocity of light*. It is termed *Weber's constant*.

From the mathematical treatment of electric and magnetic forces in Maxwell's theory, a value is obtained for the velocity of electromagnetic energy; that is, for the velocity of propagation of electromagnetic waves. In empty space this is equal to Weber's constant which is equal to the velocity of light. This must have been a great moment for Maxwell, for such a relationship of apparently different phenomena (as appraised by our senses) could not be unheeded. The result was that he identified light-waves with the electromagnetic waves which he had produced *mathematically on paper*. Could the latter be produced experimentally?

Before going further it should be stated that Maxwell's theory explained many phenomena simply and suggested relationships unsuspected hitherto. This may be said to be the usual by-product of any true (or nearly true) theory. Reflection and refraction of light were directly explained; whereas in the case of Fresnel's wave-theory, cumbersome assumptions were necessary. A number of interesting relationships between electrical and optical properties of matter were revealed or at least suggested. In fact, the electromagnetic theory of light (and of radiation in general) was a generalization which resulted in a marvelous unification of a great variety of physical phenomena which had been ob-

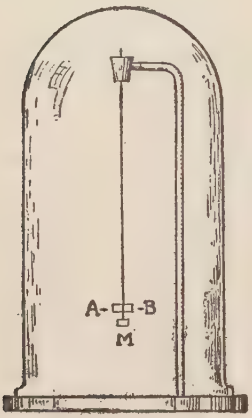
served. Ever since its formulation it has guided scientific progress. Inevitable extensions and modifications have increased its service to science. Truly, Maxwell was epochal in science, but passing away a few years later he did not live to see all the marvels he had wrought. But then maybe he is aware of them for that which we term mind may be as indestructible as matter or energy. Perhaps it is not a very distant relative of the electromagnetic forces with which Maxwell dealt.

This theory of radiation received much confirmation, as the years passed, by the results of experiments inspired by it. However, the most convincing data were contributed by Hertz (1857–1894), who in 1888 produced electromagnetic waves by purely electrical means. These waves were found to be similar to light-waves. They could be reflected, refracted, diffracted and polarized. They also had the same velocity as light. Thus the electromagnetic waves which Maxwell had deduced " on paper " now were realities; and a great theory which was built on facts, but which also boldly predicted phenomena, was placed on a firm foundation by the production of the predicted waves.

Inertia of Radiant Energy

Maxwell's theory predicted that light rays exert a pressure. This was studied as shown in Fig. 4 and Nichols and Hull verified the prediction. They originally used two silvered glass mirrors at A and B respectively. These were suspended in a vessel containing air at a low pressure. When light was permitted to fall on one of these mirrors, there was a rotation of the suspended element in a direction indicating that the incident light did exert a pressure. The rotation was measured by a beam of light reflected from the mirror M.

A demonstration of pressure of light is seen in comets. As they approach the Sun, the pressure of light from the Sun on the particles of low density of which they consist, force



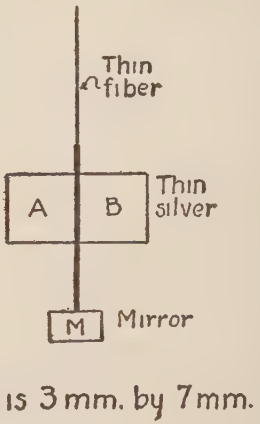


FIG. 4. An apparatus which demonstrates the pressure of light and of other radiant energy. A thin strip of silver *AB* to which a small mirror *M* is connected by a rigid support forms the sensitive element which is supported by a thin fiber. If light is incident on one side *B* of the mirror and all effects of the gas are eliminated, the suspended element twists as if the light pushed gently at *B*. The movement is detected by the displacement of a beam of light reflected by *M*. In such a manner Nichols and Hull many years ago showed that light exerted pressure — that it possessed something akin to inertia. Recently J. D. Tear greatly improved this device by enclosing *AB* and its mirror *M* in a thick brass cylinder with glass windows. The high heat conductivity of the brass equalizes the temperature which tends to vary when gas is present due to convection currents. Thus with Tear's device the pressure of radiant energy can be demonstrated at ordinary atmospheric pressures.

them outward against the gravitational attraction of the mass. Thus the tail is supposed to be produced as indicated in Fig. 5.

Light and all radiant energy are now believed to possess mass or something equivalent to it. Mass and radiant

energy are even considered to be interchangeable. It has been definitely proved that a beam of light passing close to a large mass such as the Sun is perceptibly bent toward the

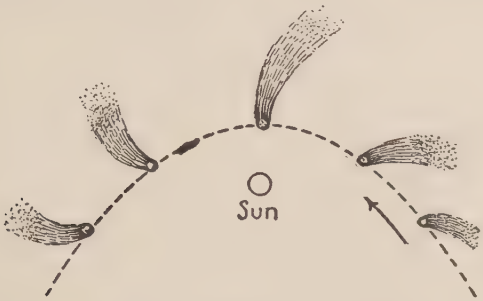


FIG. 5. The tail of a comet is probably due to the pressure of radiation from the Sun on the incandescent matter of which the comet is composed. The tail is most extensive when the comet is closest to the Sun.

mass due to gravitational attraction. (See Fig. 8.) These phases are discussed further in later chapters.

Other Radiations

Newton was the first to connect the idea of different frequencies or wavelengths to the radiations in the visible spectrum. In this manner he explained the different colors. His famous experiment must be familiar to everyone. We can see him viewing that beautiful band of spectral colors. However, he did not seem to suspect that there were other radiations present beyond each end of this colored band which caused no visual sensation. In fact, it was three-quarters of a century after he passed away before radiations adjacent to the visible region of frequencies or wavelengths were proved to exist.

At the very dawn of the nineteenth century, Herschel (1738–1822), the great astronomer, discovered that the heating effect of sunlight is not confined to the visible spectrum;

that is to the radiations that produce the sensation of light and color. He found that the heating effect extended beyond the red end of the spectrum. Thus he discovered the *infra-red* radiations of longer wavelength than the visible radiations. Hertz much later produced electric waves of very long wavelengths. Throughout the half-century that has just passed this gap has been gradually closed by extending measurements farther and farther into the infra-red and by the production of electric waves shorter in wavelength than those produced by Hertz. In fact, we now know there are electromagnetic waves all the way from the visible region out to Hertzian waves and far beyond this. Some of these in the Hertzian region are used daily in wireless and radio.

A year after Herschel's discovery, Ritter in 1801 found that the chemical action of sunlight extended beyond the violet end of the visible spectrum. In fact, this region is greater in range of wavelength or frequency than the visible spectrum. Thus Ritter discovered ultraviolet radiations. These are now known to affect the photographic plate and to have many properties not possessed by visible radiation. Some of them kill germs, some destroy animal and vegetable tissue, some of them take part in many chemical reactions. Many of these radiations have been produced and utilized by mankind.

In 1895 the world was introduced by Röntgen (1845–1923) to marvelous radiations (X-rays), which bear his name. These were emitted by a metallic target which was under bombardment of electric particles passing from one electrode to another in a vacuum tube. The fascinating property of these radiations, as is well known, is their great penetrating power. Many substances opaque to other radiations are fairly transparent to these radiations. It was believed that these were electromagnetic radiations of very short wave-

length, but owing to their extremely short wavelength (high frequency) the diffraction gratings which are used to determine wavelength of other radiations were of no use. By ruling fine lines (many thousand to the inch) a device is obtained which diffracts in such a manner that by simple mathematics and easy measurements wavelengths can be determined. However, a diffraction grating to be effective for Röntgen radiation would have to have lines thousands of times smaller than the gratings available. This could not be achieved. Physicists were in a quandary until Laue in 1912 thought of using natural crystals instead of artificial ruled gratings. Crystals were supposed to consist of regular arrangements of molecules. Laue thought that these very small particles in regular arrangement should act with Röntgen rays as ruled gratings do with light rays. His surmise proved correct and the study of these rays by means of crystals has been vigorously prosecuted. Laue's discovery has given us not only a view of the nature of Röntgen rays, but has opened up a new avenue of fruitful work.

The Curies discovered radium in 1898, three years after Röntgen's discovery. It was found that radium emitted very penetrating rays which were termed *gamma radiations*. These were found to be of a nature quite like Röntgen rays. Measurements have shown them to be of very short wavelengths or very high frequencies. Between these and the extreme ultraviolet, the Röntgen rays are placed according to wavelength. Recently Millikan extended the ultraviolet region into the Röntgen region. That is, he produced radiation from a high-voltage spark-discharge in a high vacuum of such short wavelengths as have been determined for some of the Röntgen radiations produced in the X-ray tube.

The various radiations are being produced by different methods and the whole gamut of electromagnetic waves has

been experimentally filled. All this verifies the Maxwell theory. All these radiations are of the same physical nature, differing only in wavelength or frequency. They have various properties which depend upon their wavelengths or frequencies. It is no more remarkable that flesh is transparent to Röntgen rays than that glass is transparent to visible radiations. It is no more a mystery why iron is opaque to visible radiation than that a red glass is opaque to blue light. Let us think of this whole gamut of electromagnetic waves as differing only in wavelength or frequency which, in consideration with the molecular and the atomic structure of substances, determine the opacity or transparency of the substances. The study of atomic structure of matter is daily replacing mystery by knowledge. It will eventually explain why radiations of various wavelength have different properties as measured by their effect on various substances.

Some Facts Pertaining to Radiant Energy

Although the wavelengths or frequencies of electromagnetic waves form a continuous series from zero to infinity, names have been applied to groups or ranges of them. These names have arisen in various ways, but it should be understood that there is no definite division between groups and that the only fundamental difference in any case is wavelength or frequency. The various radiations have different properties which are the result of their different wavelengths. It is helpful in presenting a picture of radiant energy to point out some properties of the various groups.

Wireless waves are those used in wireless telegraphy and radio. They are of long wavelength and low frequency.

Hertzian waves are those produced by Hertz, thereby giving an experimental foundation to Maxwell's theory.

Infra-red radiations are those just beyond the long-wave end of the visible spectrum. They are emitted by all bodies by virtue of their temperature. They accompany the visible radiation from an electric filament lamp. They are the radiation from a warm stove. The human body being of higher temperature than its surroundings is radiating these electromagnetic waves. They are absorbed by water. Glass transmits those of shorter wavelengths. Fluorite transmits further into the long-wave region than glass and rock-salt further than the fluorite. Prisms are made of rock-salt for studying them.

Visible radiations are so named because they produce the sensation of light. The long-wave limit is seen as red light; the short-wave limit as violet light. It is obvious what materials are opaque or transparent.

Ultraviolet radiations extend from the violet end of the visible spectrum to zero wavelength and thereby include Röntgen and Gamma rays. Glass transmits those of wavelengths near the visible spectrum; that is, from wavelengths 39 millionths centimeter to 30 millionths centimeter. Quartz transmits further into the short-wave region than glass, its practical limit being for wavelengths about 20 millionths centimeter. Most media absorb shorter wavelengths, even the atmosphere. Therefore, the extreme ultraviolet must be studied in a vacuum. Ultraviolet radiation of wavelengths shorter than 32 millionths centimeter are quite active in killing germs and in destroying animal tissue. They are active in producing fluorescence.

Röntgen rays, named after their discoverer, are quite penetrating. Substances opaque to other radiations are quite transparent to them. They are of the shorter wavelengths beyond what is ordinarily termed the extreme ultraviolet. They kill germs, excite fluorescence, and are absorbed effectively by lead.

Gamma rays are of still shorter wavelength, being the shortest known. They are emitted directly by the atom of certain radioactive elements. They are very penetrating. Most substances are transparent to them.

APPROXIMATE LIMITS OF FREQUENCIES AND WAVELENGTHS OF VARIOUS GROUPS OF ELECTROMAGNETIC WAVES [1]

10^{6} = one million	10^{-6} = one millionth
10^{9} = one billion	10^{-9} = one billionth
10^{12} = one million million	10^{-12} = one millionth millionth
10^{12} = one thousand billion	10^{-12} = one thousandth billionth
10^{18} = one billion billion	10^{-18} = one billionth billionth

	Frequency (Cycles per second)	Wavelength (Velocity of light ÷ frequency)
Wireless telegraphy	10^{5} to 10^{7}	10,000 ft. to 100 ft.
Hertzian electric waves	10^{7} to 10^{9}	100 ft. to 1 ft.
Infra-red radiation	10^{12} to 4×10^{14}	0.03 cm. to 76×10^{-6} cm.
Visible radiation	4×10^{14} to 7.7×10^{14}	76×10^{-6} to 39×10^{-6} cm.
Ultraviolet radiation	7.7×10^{14} to 60×10^{14}	39×10^{-6} to 5×10^{-6} cm.
Röntgen rays	60×10^{14} to 30×10^{18}	5×10^{-6} to 10^{-9}
Gamma rays	30×10^{18} to ?	1×10^{-9} to ?

[1] Wavelength equals velocity of light divided by frequency. Frequency equals the velocity of light divided by wavelength. Velocity of light is 3×10^{10} centimeters per second.

Perhaps the second-hand of a clock may help us to conceive very large and very small numbers. It would tick

a *million* times in 278 hours or nearly twelve days

a *billion* times in about 32 years

a *million million* times in about 32,000 years

If we imagine a period of *nearly twelve days,* a tick of the clock represents a *millionth* of that period.

If we think of *half our life-time,* a second is a *billionth* of that period.

A second is a *millionth millionth* of a period sixteen times that of the Christian Era; or of the period from that of the Cave Man to the present; or of the period which has elapsed since the last Glacial age.

Chapter V

WHAT IS IN SPACE?

The extent of the universe as we see it through the telescope is inconceivably large, but it is so on account of our experience which is confined to much smaller dimensions. In other words, dimensions are not based on an absolute scale, but upon the scale of our experience. Furthermore, our experience arises solely through our senses which are admittedly limited and biased. We think of atoms, as we know them, as being small planetary systems far beyond the revealing power of the microscope. Who can say that the entire universe of which we are conscious is more than a complex atom of a still greater cosmos? Who can say what is large and what is small?

The Known Universe

We have a sufficiently difficult problem to encompass in our imagination the universe known to us. Let us try for a moment to look at that from a far-off point of vantage, with eyes that telescope distances, and with a mind freed, if possible, from the prejudice of every-day dimensions. We see from that seat of the Gods great spaces in which bright bodies are moving in black space in apparent disorder. They seem to be subject to the complex influences of currents, swirls and eddies like bubbles in churning waters. Many of these millions of celestial bodies glow by their own light. Many of them are not self-luminous, but shine by light borrowed from a nearby glowing gem of great brilliancy. These occasionally

pass into shadow and become faint ghosts illuminated by distant stars. But there are no great shadows as we conceive the night sky to be as viewed from the Earth. Everywhere celestial space is velvety dark and upon this black background we are seeing the gems of the universe from the far-off viewpoint that we have assumed in our imagination.

Looking back at the region where Earth is, an insignificant part of the whole, we see this solar system which also is a very minor part. It consists of a few bodies among millions. On close observation we see this planetary system — a number of planets revolving about the Sun which is just a mediocre star. Some of these planets have satellites attending them. Our eyes range over the universe and we see thousands of nebulae twisting themselves into balls, of course, infinitely slowly as measured by our ideas of time. Here and there bushy-tailed comets dash along in apparent independence. Star-clusters as viewed from the Earth spread out over great spaces as seen from this imagined point of view.

The millions of bright gems in this dark void differ greatly in size, shape, brightness, velocity, and direction of motion. The first glimpse gives the impression of chaos. Observations of a year or two reveal systematic motion here and there, such as in the rotations of bodies and the revolutions of their satellites. A century might include more than one complete journey of some comets over their eccentric pathways. It would reveal orderliness in our solar system and in some other places. A thousand years might show enough to make it seem safe to predict that all bodies were obeying certain laws which bound them in their paths and cemented their relationships. A thousand years of observation might change our impression of chaos into one of cosmos. But this period would be too short to detect progress in nebulae toward the spherical form that they seem to desire. If we

could rid ourselves of the prejudice imposed by our experience as Earth-beings in *time* as well as in *distance,* we would then be ready to view the universe as a whole in our imagination.

Celestial Bodies

The total volume of matter in space is very small compared with the total space encompassing the known bodies. It appears that these are independent systems and celestial bodies in the space of the universe, some of whose motion is influenced little or practically none by other distant systems and bodies. If so, collisions are possible. However, the probability of such catastrophes is only about as great as collisions between a few balloons each released at widely distant points over the Earth's surface or between a dozen toy balloons bobbing around in a space equal to that occupied by the entire Earth. Even with this slight probability many collisions can occur in the eons of astronomical time. It is suspected by some that such a body as the Earth has been the result of a collision between massive stars. Small bits like the Earth may have flown off into space and because of their smallness have cooled below a glowing temperature by the simple process of loss of heat by radiation.

Obviously, we can describe what that assumed Supreme Being sees from that far-off point of vantage only in so far as we know the workings of the universe. If modern ideas are correct he would see stars of different masses, the greatest being about 230 times greater than the smallest, and that of the smallest about one-seventh that of our Sun. Densities would be found to vary from the most tenuous gaseous matter to bodies more dense than the Earth. The sizes would vary from the great giants like Betelgeuse to the most insignificant particle. Some of the largest stars are found to be of a rela-

tively low temperature of a few thousand degrees. As eons pass they may contract, becoming hotter and hotter. As their temperature increases their color changes from red, to yellow, to white, and to blue. The hottest are perhaps at least 40,000° F. After a time of increasing temperature they begin to cool, but all the time are contracting. In cooling off their color changes in the reverse order — from blue to red. Such evolutions take place over inconceivably great periods of time as measured by our standards.

Directing the observation to our known universe it seems to be shaped like a thick disc or wafer with a diameter of at least 100,000 light-years. That is, light, which travels 186,000 miles a second and comes to us from the Moon in a little more than a second, reaches us from the distant parts of the universe known to us in 100,000 years. The diameter of this disc-shaped universe is about 100 times greater than the diameter of the universe visible to the unaided eye. The latter is represented by a circle one inch in diameter if the known universe is represented by a circle nine feet in diameter. The one-inch circle represents six million billion miles. But it appears that this is not all. Our universe seems to be travelling edgewise through space, possibly a part of a parade or a party of universes. At its distant outskirts stray matter is found which seems not to belong in our known universe. Is this "driftwood," telling us that other worlds are near? How wonderful it would be if our assumed Supreme Being, possessor of All Knowledge, could reciprocate by telling us what is to be seen. We can not unfold any more of the truth because we have already reached the realm of speculation. Incidentally much of the knowledge of the universe is gained by applying our knowledge of light in relation to temperature, to elements, to motion, and to distance. Of course, light makes it possible to see these bodies, but light plays still greater rôles by doing

its tricks for us in the distant stars which we interpret in terms of its properties as we learn them on Earth.

"Through knowledge we behold the world's creation
How in his cradle first he fostered was;
And judge of Nature's cunning operation,
How things she formed of a formless mass."

Spenser

Is Space Empty?

As we look at this so-called universe from that special viewpoint, can we think of space between the material bodies as being empty? Is it not difficult to imagine this space to be empty if we must have it limitless? What can be limitless excepting *nothing?* Still, never in our experience have we seen particles suspended in nothing. Dust particles are buoyed by the air which is none the less real because it is invisible. If we could look into the atom would we see empty space again as in the universe? Certainly matter is not there because the "interplanetary" space in the atom is that between the revolving electrons and the protons. Electrons and protons by their combined movements and relations constitute an atom of matter — the smallest portion of matter known to exist. Thus in the atom we have space perhaps as apparently empty as that among the celestial bodies.

The content of apparently empty space is one of the most controversial phases of speculative, theoretical and experimental physics. Instead of our viewing the universe from that far-off point of vantage, let us suppose a Supreme Being which possessed All Knowledge was there. Let us further suppose that time and distance were unrestricted in the experiences of this special being. Surely Man on this Earth would be an insignificant detail which would cut small figure in the

doings of the universe. Nevertheless, Man's minuteness and his enforced confinement on insignificant Earth make his efforts to understand the great cosmos worthy of great respect. (Are there other living mites elsewhere struggling to know?) We can imagine this Supreme Being nod approval of Man's quest, but sometimes there must be a flicker of a smile on the countenance of that observer possessing all knowledge. Man is seen poking about here and there; now completely blocked and then finding a promising avenue. Of all the phases of Man's development of science, there could be no greater source of amusement for that special observer than Man's wrestle with apparently empty space. Notwithstanding its apparent emptiness Man has filled it with a hypothetical medium primarily to make it possible to conceive "action at a distance." He had to have a carrier of light-waves, therefore the ether was invented and endowed with certain properties. As science advanced these "properties" have been altered. Now we find ourselves divided not only as to its properties, but even as to the necessity of its existence. It can scarcely be said that the invention was ever satisfactory.

The Hypothetical Ether

It is difficult for us to account for the action of one body upon another without conceiving a connecting medium in which the stresses and strains can be transmitted or continued. Newton attempted to account for the attraction of the Earth for a body by differences in pressure of an ether, but he did not emphasize this view because he was unable from experiment and observation to give a satisfactory account of this medium. Many of his followers did not bother about accounting for the force of gravitation and the attractions and repulsions of electrified and magnetized bodies. They

were satisfied to record data and to establish laws without trying to account for these forces. However, there were many who invented ether of various properties in order to explain phenomena and to construct "working models," without being able to prove its existence or even the existence of any of the properties which they had bestowed upon it. Therefore, there is much room for argument as to the value, if any, of most of these inventions of an ether. It is questionable whether anything is eventually gained by trying to explain by means of a hypothetical medium of assumed properties. Still the idea of an ether has been helpful at least "along the way."

The wave-theory of light, as propounded first by Huygens about a century ago, gave rise to a seemingly necessary medium through which the waves could be transmitted in otherwise empty space. If we were to look upon light as waves, certainly there must be something in which the waves can exist. A medium in which waves are transmitted must have elasticity and inertia or something equivalent to them. The medium must be elastic in order to store up energy for the rebound. It must have inertia in order to overshoot the neutral point. By means of these two properties or equivalent ones, we obtain oscillation or wave-motion. A bar of thin spring steel with one end held in a vise is an example. By pulling back the free end and releasing it we have vibrations due to the elasticity and the inertia of the piece of metal. The vibrations rapidly diminish and finally cease; hence, the properties of the metal may not be considered ideal for an ideal ether in which no perceptible loss in energy is noted. The property analogous to elasticity may be any fitting restoring force; that analogous to inertia may be any fitting tendency toward persistence of motion. Owing to the fact that light-waves are transverse in nature, according to the accepted theory of elasticity, the ether must be equivalent

to an elastic solid. But the properties which the ether must have in order to transmit the mechanical waves of light, as conceived by Huygens, were incompatible with our experience with space. Really our experience with the ether was *no experience* because it had not been shown to exist. Here was the rub. We or the celestial bodies, or even light-waves themselves, yielded no testimony of having actually had any experience with the ether. For example, how could the ether behave like an elastic solid for light-waves and still offer no known resistance to the relatively slow movements of celestial bodies? In the latter case it must be a perfect fluid.

When it was proved that light was not matter, but a process having the earmarks of wave-motion, we had to have a substance for the process to take place in. The phenomenon of interference represents the kind of experience which encouraged the belief that light was not a substance. When two series of light-waves, properly out of step with each other, fell on a white surface a series of alternate dark and bright bands appeared. In the dark spaces the light of one beam had destroyed the effect of the other beam. Is it possible to conceive that two substances when added would equal nothing?

Light-waves travel to our eyes from many distant stars, therefore so-called ether must fill all space. If the ether must be a solid in order to transmit transverse waves such as those of light are known to be, we must conclude that space is filled with this peculiar medium no part of which moves with respect to another part with the exception of the small "movements" corresponding to light-waves. Many experiments have been performed for the purpose of detecting a movement in the ether. All matter is known to be very porous and the ether of space must permeate all matter. A moving object, therefore, might carry ether with it. The Earth plunging through space might cause at least a drift of ether near it.

This idea led to many experiments including the Michelson-Morley experiment. (See Fig. 3.) In this a beam of light was divided, one-half being sent to and fro across the supposed ether drift; that is perpendicular to the Earth's motion. The other half was sent to and fro in the direction of the Earth's motion. The time required for travelling equal distances in these two directions should be slightly greater for the one parallel to the Earth's travel. Any difference in velocity would be noted by a shift of the interference bands. (This interference method is a very sensitive method of measurement applied in many ways in physics. It measures in terms of the very minute wavelengths of light.) Not the slightest difference was detected in the travel of light in these paths at right-angles even though the accuracy of the measurements were one in four billion. In other words, this accuracy is equivalent to measuring one thousandth of an inch in a distance of sixty miles. The natural conclusion was that there is no ether drift or that the ether is stagnant or that the Earth carries all the ether near it along with it. However, Einstein in recent years has proposed an explanation which is presented later.

When Maxwell developed the electromagnetic theory of light he still needed an ether as a carrier of the waves. The laws which he developed are straightforward and simple, but his ether model was complicated and of very special properties. However, with the introduction of electric and magnetic concepts these began to claim attention and the difficulties of mechanical interpretation of the ether were gradually more or less ignored. But this lack of attention to the mechanical model did not eradicate the difficulties and unsatisfactoriness. There was a tendency to explain mechanics in terms of electromagnetic principles. This seemed to be a way out, nevertheless, it was not successful. Matter finally was supposed to be a bearer of electromagnetic fields and, in-

asmuch as such fields are found in a vacuum, the ether had to have its properties extended. Always ether possesses functions of ordinary matter, therefore, it grew more complicated as the properties of matter were extended.

Lorentz harmonized theory and experience when he extended Maxwell's electromagnetic theory of light by introducing the electron theory. He took the mechanical properties from ether and the electromagnetic properties from matter. According to his view the ether in material bodies was the medium in which electromagnetic fields existed even as in the case of a vacuum. Einstein credits Lorentz with having taken from the ether all mechanical properties excepting immobility. Einstein by his special theory of relativity so altered the conception of the ether that he did not leave it even immobility.

But the controversy still rages. With the introduction of the theory of relativity, the existence of an ether has been much discussed. The theory apparently does not need any ether, but is not incompatible with it. Einstein's view is that it is inconceivable that we can ever detect any motion between matter and ether, but this does not mean that there is no such medium. The relative motion between matter and ether, if it exists, is masked because the velocity of light and other electromagnetic waves in otherwise empty space is identical (probably) with the velocity which is found in Einstein's relativity equations for changes in time, space, and matter with motion. If these changes are accepted, then experiments with light-waves cannot detect either ether's existence or non-existence. Of course, there remains the possibility that ether, if it exists, may possess some property besides the ability to transmit electromagnetic waves which is not accounted for in the new theory of relativity. However, such a possibility appears remote. Nevertheless, an ether may exist.

Unknown Worlds

This is the brief story of space and of what it contains and may contain. The actual material of space consisting of the matter of celestial bodies is a very small part of the whole. If ether exists, it is all-pervading and highly important, more so perhaps because of our inability to detect it than if it were easily detectable. If it exists, our utter unconsciousness of it makes it possible for it to be much more vital to the universe than any ordinary medium could be. Perhaps this emphasizes the extreme limitations of our human senses in appraising all that may exist in the universe about us. With our mere human senses we may be living in a world within a world. Anything is possible beyond our experiences. Our imagination could conjure up another world coincident with our "human" world, but unseen, unfelt, and unknown to us. Although we know a great deal of the physical world in which we live, beyond the veil unpenetrated by our senses may be other worlds coincident. These may be the realms of spirits released from the shackles which limit us and the penetration of our senses to this physical world. But even this great physical universe and those numberless ones that may exist beyond the reach of our telescopes are marvelous, though Man has achieved only a glimpse and only slight knowledge. There is much to keep science busy unveiling it. Doubtless eventually far distant universes, if they exist, will be revealed to our eyes. If there is a world coincident with our physical one, will we ever surmount the handicaps of our senses and reveal its reality — and perhaps its inhabitants? Is there

"One God, one law, one element,
And one far-off divine event,
To which the whole creation moves."

Tennyson

Chapter VI

THE VELOCITY OF LIGHT

If we toss a ball to another person, it is obvious that it takes time for the ball to travel the distance to the other person. If we shoot a bullet at a target, we find greater difficulty in noting the short interval that intervenes before the bullet strikes the target. Sound travels in air of ordinary temperature and pressure about 1100 feet per second; in hydrogen and in water at about four times this velocity; and in solids at velocities much greater than that in air. Incidentally, this is contrary to our experience with light because light travels more slowly in glass, for example, than in air. This shows one of the characteristic differences between the *longitudinal waves* of sound and the *transverse waves* of light. It is not difficult for us to detect that most objects, and also sound, take a certain amount of time to travel from one place to another. However, light travels with such an enormous velocity that it was considered an instantaneous phenomenon in early centuries. Nevertheless, its velocity was determined at a surprisingly early date considering the state of scientific progress at that time.

The velocity of light through stellar space or in a vacuum is about 186,000 miles per second. It is practically the same in air. Light and, in fact, electromagnetic waves such as those used in radio could travel around the earth nearly eight times in a second. Eliminating any lag in the sending and receiving radio-stations we can hear a spoken word transmitted by radio at a distance of 1000 miles from the speaker before

persons ten feet from the speaker would hear it. Light and other electromagnetic waves travel nearly a million times faster than sound waves in air.

A Fundamental Factor

The great velocity of light is in itself interesting, but this is not a reason for its consideration as fundamental in the scheme of the universe. However, as science progressed, surprising relationships have sprung up in which the velocity of light is an important or even an elemental factor. If an electric current is measured by the quantity of electricity which passes any cross-section of the conductor in a second, a certain value is obtained. If it is measured in terms of the magnetic field around the conductor which the flowing electricity sets up, another value is obtained. The ratio of these units of electricity is not a pure number, but a velocity; and this velocity is equal to that of light. It is known as *Weber's constant* after the man who first determined the ratio. This was known before Maxwell developed his electromagnetic theory of light. A result of Maxwell's theory was that the velocity of propagation of electromagnetic waves was equal to Weber's constant. This revealed the theoretical possibility of the identity of light-waves and electromagnetic waves.

The importance of the velocity of light as an elemental factor was not to rest here. When the electron was discovered to be an "atom" of electricity and an important part of the structure of an atom of matter, new concepts appeared. Mass now appeared to be due to the electric charges contained by the atoms. This could be tested by determining the kinetic energy of an electron due to its motion, the velocities, and the charges associated with the atoms. J. J. Thomson proposed this idea of *electric mass,* and thought of mass not so much

as a property of the electric charge itself, but more as a property of the space surrounding the charge. This space contains potential energy owing to the fields associated with the electric charge. As the charged particle or electron moves, this potential energy moves with it. Experiments indicated that mass is apparently constant at ordinary velocities; in other words, that Newton's ideas were practically correct. However, when moving charges, such as the electrons expelled by radium, attained velocities approaching that of light, their mass increased. This was in accord with the results of Thomson's assumption that the mass of a charged particle is due to its charge. It is sufficient at this point to state that these experiments and the underlying theory indicate that the mass of a particle carrying a charge becomes *infinite* at the velocity of light. Inasmuch as atoms of all matter are now thought to consist of electrons (negative charge) and protons (positive charge), it follows that the mass of any body becomes infinite at the velocity of light. If the mass remained constant, we could go on increasing the velocity of the body by increasing the force applied, until the velocity became infinite. But when the mass becomes infinite at a finite velocity (that of light) as appears to be the case, it is obvious that no force can increase its velocity. Therefore, the velocity of light is the highest attainable velocity. Thus it becomes a noteworthy factor in the scheme of the universe in a very fundamental way.

If the mass of a body increases with the velocity of the body, Newton's laws fail to be dependable when this increase in mass becomes noticeable. However, most of us need not worry about the matter even though we find it interesting. At ordinary velocities of trains, airplanes and even projectiles fired from guns, the increase in mass is undetectable, but it may be computed from the laws that have been derived. If at the

Earth's surface a body weighing 100 tons (say a locomotive) has a velocity of 60 miles per hour it will weigh about *one billionth of a pound more* than when at rest. A body must travel at the tremendous velocity of about *160,000 miles per second* to have double the mass that it has at rest. This is not far from the velocity of light at which velocity the mass becomes infinite. The effect of mass is seen to become noticeable only at high velocities.

Effect of Theory of Relativity

Einstein introduced the doctrine that space, time and matter may be different for different observers; that they are relative and not absolute as Newton assumed. According to this principle it is impossible to detect a relative motion of ether and matter, because space and time change with motion in such a manner that the velocity of matter through ether is equal to zero. This means that all observers regardless of their motion will obtain the same value for the velocity of light. Thus the velocity of light attains a universal significance. It is the same in all directions for all observers.

If observers moving at different speeds appraise lengths and masses and times differently, it is obvious that *simultaneity* becomes meaningless. Of course, these matters become serious only for extreme velocities. Incidentally, there is loss in time just as there is increase in mass. A velocity which doubles the mass of a body (measured in terms of the mass at rest) makes a watch run only half as fast. In other words a watch would lose 12 hours a day at a velocity of about 160,000 miles per second. At the velocity of light the watch would lose the entire 24 hours in a day. (See Fig. 6.) If we could impart to our bodies a velocity of light the entire panorama of world history would pass by in an instant. But we must not for-

get that space would be shortened to zero; that it, the dimensions of all objects in the direction of relative motion would shorten to nothing. Incidentally, our money "goes fast enough" usually, but there would be an advantage in giving a gold piece the velocity of light provided we could spend it under those conditions. Its mass would then be infinite.

These ideas introduced by Einstein may seem weird and metaphysical, but they are not. They are based upon observed facts. They have passed several tests with glory. But they are discussed further in the proper place. They are introduced here merely to indicate that the velocity of light has become a fundamental of universal significance. The theory of relativity gives it a part in the physical world similar to the part played by infinity in mathematics.

An Interesting Relation of Electrical Units

It may be of interest to examine the relationship of two electrical quantities, because it emphasizes the enormous velocity of light and exemplifies the intricate manner in which it is interwoven into the affairs of the physical world. Electrical quantities and their relations to each other and to other quantities are full of surprises. Being slaves to those dimensions of space and time with which our activities and welfare are more immediately concerned, we find difficulty in conceiving the smallness or the largeness of many quantities associated with electricity. For example, let us consider the coulomb, equivalent to an ampere flowing for one second. This is a quantity of electricity which is easily obtained and is familiar to all of us. An ordinary dry-cell is a source of thousands of coulombs. On short-circuiting this dry-cell for a moment several coulombs flow. Thus in our experience the coulomb is a commonplace quantity, easy to obtain, and, there-

fore, we little suspect what potentiality this commonplace coulomb may possess. Let us see what force it may exert.

If we place an electrostatic unit charge on a point and a similar one on another point one centimeter distant from the first, the force of attraction (or of repulsion) exerted between them is one dyne. The coulomb is of the electromagnetic system and is 3×10^9 times larger than the unit charge of the electrostatic system. Consequently these two coulombs on points respectively one centimeter apart would exert a force between them of 9×10^{18} dynes. Expressed loosely it is approximately equivalent to 10^{10} tons (at the earth's surface). This force of ten billion tons would be duplicated by all the persons on the earth pulling together at the end of a rope if each person could exert a force of approximately five tons. Such a force is equivalent to the weight of a million large steamships at the earth's surface.

Still this force is the attraction or the repulsion of two commonplace coulombs on points one centimeter apart. To most of us doubtless this is astonishing and perhaps unbelievable until investigated further. Of course, the surprisingly large figure is due to the relation between the electrostatic unit and the electromagnetic unit involving a factor equivalent to the velocity of light. In fact, this extremely large constant has a habit of creeping into many electrical relations with surprising results.

Another thing worth considering is the difficulty of placing these two coulombs one centimeter apart. The amount of work required to accomplish this is just as surprisingly large as the figures already presented. So that besides indicating the tremendous electrical force which is associated with two commonplace, apparently insignificant coulombs, we also again experience the familiar axiom that a certain work equivalent is a necessary part of an accomplishment.

Measurement of the Velocity of Light

The discovery that it takes time for light to travel through space was perhaps first made by Roemer in 1675 by observations of the satellites of Jupiter. These "moons" revolve around Jupiter regularly. When the Earth is farthest away from Jupiter there is a delay of over 16 minutes in the time at which any one of these satellites enters Jupiter's shadow as compared to the time of the same event when witnessed from the Earth when it is nearest to Jupiter. This means that light takes over 16 minutes to travel across a distance equal to the Earth's orbit, which is 186 million miles. Inasmuch as it is difficult to determine the exact moment when the satellite enters the planet's shadow, this method is not very accurate.

Another astronomical method depends upon the aberration of the fixed stars. Owing to the fact that our Earth, and consequently the observer, is moving, the star will not appear in its true position. It will appear displaced in proportion to the observer's velocity divided by the velocity of light. Inasmuch as the Earth in passing around its orbit will be moving in different directions, the apparent displacement of the star will describe a small orbit (around its true position) in the course of a year. The displacement is very small being a maximum of only about 20 seconds of arc. However, this can be measured accurately enough to give a value closely approximating the true velocity of light.

A number of methods have been devised for measuring the velocity of light on the Earth. Fizeau in 1850 passed a ray of light through slits in a wheel to a mirror which reflected the light back to the wheel. If the latter was rapidly rotated by the time the light returned over its path the slit through which it first passed may have been replaced by an opaque portion. By using proper distances, fine slits, and accurately timing

the wheel, a measure of the velocity of light was obtained which checked closely with the values obtained by the astronomical methods.

Naturally refinements were made as science progressed. A later method consisted of reflecting a ray of light from a rapidly rotating mirror to a fixed mirror and back to the first mirror again. If sufficient time elapsed before the light returned, the rotating mirror will have rotated slightly and the returned ray will be reflected in a slightly different direction than if the rotating mirror had been at rest in the meantime. By making the proper measurements the velocity of light is obtained.

Inasmuch as light-waves have various wavelengths or frequencies (which cause the different sensations of color) the question arises, Do all electromagnetic waves travel with equal velocity through space? There are now many reasons for believing they do, and there is little doubt that this question has been practically settled by experimental data. By observing the eclipses of variable stars at distances so great that it takes light 100 years to reach us, light of various wavelengths seems to reach us simultaneously after the eclipse has passed. Incidentally we view such an eclipse 100 years after it has occurred, but in viewing its beginning or its end no difference in the time of arrival of the light-waves of different frequencies (or color) is detected. Considering these great distances it may be said that, to a very high degree of accuracy, the velocities of all light-waves are equal. Of course, the question is settled only in so far as we are satisfied with the degree of accuracy of the measurements. This is always the case of experimental proofs.

Light-waves are considered to be invariable in length and in frequency in a given medium. They offer a very small unit for determining small magnitudes and even large ones. Michelson has used them to determine the platimum-bar stand-

ard of length in Paris. Many have measured small dimensions in terms of them. Light-waves of the shortest wavelength producing the sensation of light (violet) are so small that it takes about 65 of them to equal one thousandth of an inch. The longest wavelength (red) which produces the sensation of light is about twice as large as the shortest one.

In our everyday experience the velocity of light seems to be infinite because it travels earthly distances in such very small fractions of a second. However, when we consider astronomical distances we readily see that light travels with a finite velocity which is rather low when such great distances must be traversed. Polaris, the North Star, is so far away that it takes light about 75 years to reach us from that star at which the Earth's axis points. But this is an insignificant distance compared with distances already determined with certainty. For example, the small Magellan cloud is perhaps 35,000 light-years away and it seems that the distance of the star cluster in Hercules is so far away that it takes light about 100,000 years to reach us from it. If we were sitting on the star, Rigel (466 light-years distant), with an all powerful telescope we would have to wait 34 years more before we would see Columbus discover America. Why did not Jules Verne think of these various stars reflecting images of Earth-happenings to Earth-beings equipped with super-telescopes? In such a mirror 100 light-years away we could see reflected the events on Earth which were taking place 200 years ago. From a mirror on a celestial body twice as far away as Rigel we might witness the Crucifixion of Christ. With mirrors on other celestial bodies at various distances, Earth-beings could turn back the pages of history at will. What a group of motion-pictures of various ages of civilization we would have before us at all times! What historical pageants could be reviewed by this means!

Chapter VII

THE EPOCH OF EINSTEIN

Space, time, and matter are the foundations of our physical universe. Physical science consists of determining the constitution of matter and of revealing the relationships of these fundamentals in various phenomena or processes. Not all these processes are revealed to our limited senses, not only because some magnitudes of distance, time and matter are beyond the ability of our senses (too small or too great), but also because we do not possess special senses which can react to some of these processes. We have seen how Newton and his predecessors and contemporaries considered these fundamentals and how the wave-theory of light demanded a medium in which light-waves could be propagated. Action at a distance could not be reconciled with human experience. Therefore, the ether was invented and it was conceived to fill all space. This special medium, which has never been detected, offered no difficulty to the imagination, but it has caused much difficulty practically. As science advanced, its assumed properties had to be modified to satisfy new knowledge, but a satisfactory model of it was never constructed in theory (and its existence was only in theory as far as actual knowledge was concerned) as long as it had to satisfy "mechanical" processes. Later conceptions removed some difficulties, but it may be said that the need for an ether decreased in importance about in proportion to the removal of difficulties by the more modern conceptions.

Does the Ether Move?

The ether was assumed to exist throughout stellar space because light travels from celestial bodies to our eyes. It must also fill inter-molecular space because light passes through transparent bodies and also through "opaque" ones if they are thin enough. Filling all space and being infinite in extent, it was natural to consider that the ether is stationary. This led to much discussion and various experiments. Among the latter the most famous was the Michelson-Morley experiment performed in 1887. (See Fig. 3.) Notwithstanding the utmost refinements of the measurements involved, no trace of the motion of the Earth with respect to the hypothetical ether was detected. Science was in a quandary and remained so until Einstein propounded his now celebrated theories.

This experiment is so important that it will be described in detail. If the Earth is moving through the ether as indicated in Fig. 3 and the ether is stationary, the velocity of the Earth with respect to the ether is of a certain (unknown) value. If a light-source is placed equidistant from two mirrors *A* and *B*, it should be obvious that light will travel to mirror *A* and back in a shorter time than to mirror *B* and back. The time required for light to travel to and fro on these two paths at right angles to each other can be readily computed in terms of the unknown velocity of the Earth relative to the supposed ether. If this is not obvious let us assume that the ether is replaced by water flowing at the same unknown velocity of the Earth relative to the ether. The direction of the flowing water would be from right to left or opposite to the indicated direction of the Earth's motion with respect to the ether. The principle will be clear at once if we assume that a swimmer is able to swim with a velocity just equal to the velocity of the flowing water. He could swim from the posi-

tion of the light-source to the mirror *A* by steering a course at an angle toward the right and could get back to the position of the light-course by angling toward his left. However, he could never reach the mirror *B*, because, if he could swim only as fast as the current, he could not leave his original position at the light-source.

Of course, the velocity of light was considered to be much greater than the velocity of the Earth with respect to the ether. In fact, Michelson and Morley were prepared to measure a very small difference in the time required for light to pass to and fro over equal distances in the two directions at right angles to each other. Notwithstanding the application of the most refined methods of optical measurement, their experiment failed to reveal any influence of the Earth's motion on the velocity of light. They turned their apparatus at various angles and repeated the experiments at various times of the year, but the results were always the same — no difference. This experiment baffled scientists for years and it may be said to be the starting point for the great work of Einstein who first propounded the principle of relativity in 1905 and since that time has made many other valuable contributions to theoretical physics.

The Principle of Relativity

For ages Man has been certain that if he described the location of an object in respect to other fixed objects that he conveyed a very definite idea to another person which would be the same for all persons. If he said he would meet someone at this object in thirty minutes, both would know the exact time of the meeting. Here we have space, time and matter involved and the certainty of the foregoing meeting-place and of the time of the meeting depends upon the as-

sumption that *space* and *time* mean the same things to all persons. In everyday experience they do, but they apparently do not when we deal with very high velocities and various phenomena found in the universe outside our daily experience.

We can measure in two distinct ways the length of a rod which is moving in the direction of its length. We can measure it by moving with the rod or two stationary men can note the positions of the two ends simultaneously on a stationary tape. Our experience predicts that the two measurements will be identical. However, if this rod were moving at a high velocity of 160,000 miles per second or if it were so long that

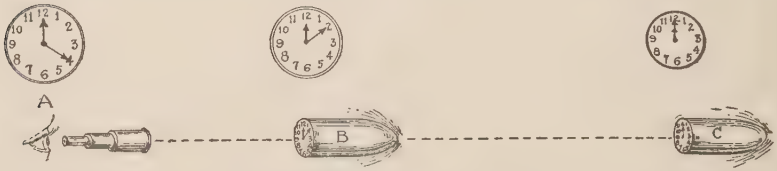


FIG. 6. Two projectiles (each containing a clock) are assumed to leave the point *A* simultaneously at twelve o'clock and to be observed by a stationary observer at the point *A*. The projectile *C* is assumed to have a velocity equal to that of light (186,000 miles per second) and projectile *B* is assumed to have a velocity of 160,000 miles per second. To the observer at *A* the clock on *C* appears always to indicate 12 o'clock. The clock on *B* appears to run half as fast as it should, because we choose the correct velocity according to the Einstein theory to make it appear so. For example, twenty minutes after the projectiles were fired *B* would be at a distance about equal to that of the Sun from the Earth and its clock, instead of registering 12:20, registers 12:10.

at an ordinary speed it took a thousand centuries to pass, who can say whether or not the two methods of measurement would yield identical results. Einstein says they will not, and his theory has stood several tests so well and it accounts for hitherto unexplained results with such satisfaction that, at least, we cannot safely contradict it. (See Fig. 6.)

Einstein considers that statements of time have only *relative* significance. In other words, two observers in motion with respect to each other will state time differently. There is no easy way of testing this principle by experiment. Perhaps there is no way at all within the possibility of human beings. About all we can do is to see if it explains facts which can be explained only with great difficulty, if at all, by considering time *absolute* instead of *relative*. The Michelson-Morley experiment and some astronomical data are facts which the principle of relativity of time and space have accounted for in a glorious manner.

The Einstein principle cannot be represented by a model which we can readily conceive. It can be represented satisfactorily only by mathematics. It is of four dimensions because the dimension *time* is added to the three dimensions of space. Einstein's imagination broke the shackles of human experience and journeyed off into space where it looked at *events*. It came back to Earth and explains them in terms of our space, time and matter. Besides postulating that all statements of time in describing a physical process are *relative* and dependent on the viewpoint of the observer, this principle holds that all statements of time must be such that the velocity of light in terms of them *must be identical in all directions for all observers*. Thus the velocity of light becomes a foundation stone.

Naturally, if there can be no absolute measure of time, there can be no absolute measure of length or space. An observer moving in the direction of the length of a rod will state that the rod is shorter than it appears to an observer who is at rest relative to the rod. An observer on Earth might determine the rod to be ten feet long, but to an observer on the Sun this rod on Earth would be slightly shortened. Similarly, an interval between two events on the Earth would appear slightly longer

if viewed from the Sun. Thus *simultaneity loses its meaning*. If an object appears of different lengths to two observers in motion with respect to each other, then *shape* also *becomes relative*. All these " distortions " of space and time are negligibly small excepting at very great relative velocities; nevertheless, they are sufficient to explain various facts. Inasmuch as velocities greater than that of light are impossible according to this principle, the velocity of light has a property similar to infinity in mathematics.

Such statements as the foregoing without full proof and representation by models, at first seem paradoxical and even fanciful. Owing to the difficulty everyone has in comprehending them, the theory of relativity suffered much opposition and some ridicule. Nevertheless, scientists soon began to appreciate that a great philosopher had propounded a principle of far-reaching importance.

Four Dimensions

Mathematics finds no difficulty in dealing with more than three dimensions, but our human minds have had no material experience with more than the three dimensions of space. We can locate any point in the space bounded by the walls of a room by measuring the perpendicular distance of the point from three planes of reference, such as the floor, the south wall, and the west wall. (See Fig. 7.) These measurements locate this point absolutely for the observer under the particular condition. In other words, the three dimensions of space as we know it, are up and down, right and left, and to and fro. To these Einstein adds *sooner* and *later*.

Let us locate the point P in the room represented in Fig. 7 where A is a corner made by the intersection of two walls and

the floor, each at right angles with the others. The point P is 5 feet above the floor, 6 feet from the south wall and 2 feet from the west wall. Simple geometry demonstrates the fact that the distance from P to A is equal to the square root of the sum of the squares of the three quantities $\sqrt{5^2+6^2+2^2}$ or $\sqrt{65}$ or approximately 8 feet. Obviously, no matter how this room is turned the foregoing result is correct. It should also be

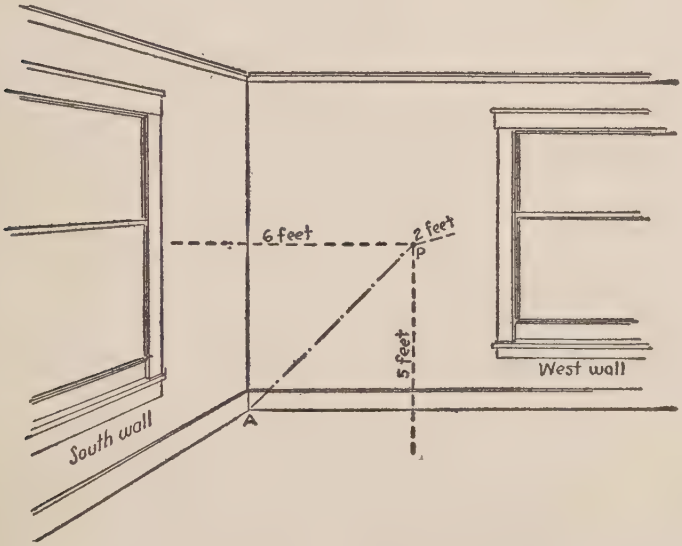


FIG. 7. The point P may be located as shown by the distances from each of three planes (two walls and floor) respectively. The distance PA is equal to the square root of the sum of the squares of the three distances or, $\sqrt{6^2+5^2+2^2}$.

obvious that the location of the point P could be achieved by using any other three planes of reference and still the distance from P to A would remain the same. A group of observers at rest in the room would agree as to the distances and the sum of their squares (65).

But according to the principle of relativity if an observer is in motion these distances are altered. In other words, we must view the existence of the point P and the corner A as *events,* because perception requires time. Furthermore, there is always the likelihood of motion and there is always the parade of time. A time dimension must be introduced, but in a manner which gives us the same result as we obtained in the old method. Here is the difficult gap for the imagination to span. Einstein considers P and A to be events. (Perhaps it may help us to think of two different happenings at these points, such as the arrival of a fly at the corner A and one at the point P.) The total interval between the P and A consists of a space interval and a time interval. The square of the space interval is $5^2+6^2+2^2=65$. Suppose the time interval is 6 units. We must agree upon some time unit such as a pendulum vibration and upon some basic velocity that will be a uniform velocity for observers anywhere. The velocity of light is chosen for this and, as already stated, is one of the foundation stones of the theory of relativity.

Proceeding with the specification of the two events P and A, we find the square of the time interval to be $6^2=36$. According to Einstein's mathematical philosophy, the *square of the space-interval* minus the *square of the time-interval* of any particular combination of events is constant throughout free space. Where there are strong gravitational forces this relation is slightly modified. In terms of our example, $5^2+6^2+2^2-6^2=29$. Inasmuch as $(\text{space-interval})^2$ minus $(\text{time-interval})^2$ must be the same if we are in motion relative to the room or for any condition, let us test a particular case. Suppose now our relative velocity is such as to give a distance of 7 feet between P and A. According to the principle of relativity the time-interval must be such that its

square subtracted from the square of the space-interval is equal to 29. In our case we would have

$$7^2 - (\text{time-interval})^2 = 29$$

The time-interval would be $\sqrt{20}$ units or not quite $4\frac{1}{2}$ units.

It should be noted that the principle is based on definite assumptions which appear to be correct, because the laws erected thereon fit the facts of observation. By injecting this temporal quality into statements of events, Einstein makes it possible for an observer anywhere under any condition to obtain the same apparent measurement of space. For example, the length of a rod would be determined to be the same whether measured on the Earth or on any other celestial body by the same observer and measuring device. This does not mean that the length of the rod is the *same* in all cases and it does not imply that any of the measurements reveal the *true* length. Constancy of length and true length have no meaning in this great generalization and unification. To two observers moving uniformly with respect to each other (one on Mars and the other on Earth) the rod does not appear of the same length, but Einstein provides a means for these two observers moving with a uniform relative velocity to arrive at the same mathematical statement of the phenomena.

Many persons in trying to grasp this new conception of relativity of time and space, give up when introduced to four dimensions. However, it should be noted that a fourth dimension has not been given to space. The same tri-dimensional space is retained, but time is introduced as a fundamental factor. The universe does not exist as far as we are concerned excepting as events. The four dimensions are merely mathematical. Four measurements must be reckoned with in our statement of the relation of two events. There is a certain relationship of these four measurements which is constant for all observers regardless of time and space.

The principle of relativity should not be considered as beyond the conception of our minds for it is not. It changes none of our everyday practices. It accounts for discrepancies between our older laws and the actual facts which in most of our experience are very, very small. It merely replaces a given set picture of Nature (space and matter) with an infinite series of pictures. We see a certain relationship of matter in space which is the setting of our study, for example. To a person moving with relation to the setting, the relationship of the matter and space changes — the setting shortens in the direction of motion. If a single object, among many, changes its relative velocity, its appearance (and mass) alters. The minuteness of these differences between fact and older theory is doubtless responsible for the delay in the appearance of such a theory.

Effect on Newtonian Mechanics

Although the practical effects of the principle of relativity are so small as to be generally negligible in our everyday affairs, the effect on scientific progress toward a unification and explanation of Nature is very great. Newton's laws still hold, but they are for the special case of velocities which are small in comparison with the velocity of light. Mass in Newton's laws is considered to be constant. Our idea of mass has been that it indicated the amount of matter in a body. The motion of a body according to Newton's laws depends upon its mass and its velocity. A change in either reveals the existence of a force. This is now considered merely an approximation to the truth, not only in the light of the theory of relativity, but also of actual experiments. If the velocity of a body relative to an observer is great enough, there are found to be observable deviations from these classical laws of mechanics.

Long after Newton's time, in fact, in the latter part of the nineteenth century, small particles were discovered which moved with great velocity. For example, electrons (unit electric charges) are emitted by radium and by other matter under certain conditions. Some of these have great natural velocities; others can be moved very rapidly by applying electric forces. As the velocities of these particles approach the velocity of light (relative to an observer), their mass is found to increase. It doubles at a velocity about seven-eighths that of light. It becomes infinite at this highest attainable velocity. To those who wish to see the relationship expressed with the simplicity and clearness of mathematical form, the following relationship is presented:

$$M_v = \frac{M_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

M_v is the mass at any velocity v of the body relative to the observer.

M_o is the mass of the body at zero velocity relative to the observer. This may be termed the *stationary mass.*

c is the velocity of light.

It is seen that when v is zero the formidable appearing denominator reduces to unity and $M_v = M_0$. Under such conditions the denominator becomes $\sqrt{1 - 0}$ or unity. When the velocity v of the body equals that of light c (186,000 miles per second) the denominator becomes zero because it becomes $\sqrt{1 - 1}$ and the mass M_v becomes infinite.

The reader should find it of interest to compute the mass of a body for various velocities v relative to the observer.

Before Einstein presented his conception of the relativity of time, Lorentz made the assumption that any body in motion appeared shortened in the dimension in the direction of

relative motion. He offered this as an explanation of the results of the Michelson–Morley experiment. It follows from Einstein's work that this shortening is inversely to the increase in mass. That is, if an observer could watch a body gradually increase in velocity, it would appear to shorten as it attained high velocity. At 160,000 miles per second it would appear to him only half as long in the direction of motion as it did at rest. As the velocity increased further, it would appear to shorten more rapidly and would be of zero dimension in the direction of motion at the velocity of light. To a person riding on the body no apparent change in length would take place.

J. J. Thomson in 1881 introduced the idea of electrical mass. He pictured mass not as a direct property of the particles with which he dealt, but as a property of the region (ether) surrounding the particle. We can conceive electromagnetic stresses in the ether in the vicinity of electrical charges of which matter is thought to consist. When the particle moves, this potential energy or "field" is carried along. As the velocity of the particle increases there is, according to Thomson's view, a tendency for the "field" to concentrate in an equatorial plane perpendicular to the direction of motion. We will leave this matter for further discussion later, but the reader is given this glimpse which may suggest a picture of the increase in mass with increase in velocity.

It may appear to the reader that the new concepts give us a picture of an unreal world in which we cannot be certain of anything. The picture of Nature is a very definite one, but begins to distort as we move. That is just what takes place, but we are not generally conscious of it. Some of the effects we may never actually detect by experiment; others are so special that they can be detected only by very careful experiments under certain conditions. These are the reasons

why Newton's laws for so long were considered to explain Nature accurately instead of, as we know now, only approximately. By introducing the factor of relative time and by the aid of new knowledge, Einstein has given us a " universal language " for describing Nature. If instead of being Earth-Beings, we were freed from all the shackles and handicaps of Earth and of our human bodies, it appears that the Einstein language would be quite necessary. The ideas involved have put the finishing touches on the classical laws of Nature as they had been devised by Newton and others. But in conceiving the principle of relativity which achieves such universality, perhaps Einstein has revealed the language of Gods and Spirits.

We are reminded of what Byron says of us beings of Earth.

> " But we, who name ourselves its sovereigns, we,
> Half dust, half deity, alike unfit
> To sink or soar." *Byron*

Other Consequences

With the introduction of the principle of relativity, a new horizon presented itself. Those who paved the way for Einstein — Thomson, Lorentz, Planck and others — added important discussions and ideas. An army of scientists went into the field in search of proofs and new data. Einstein himself in a series of contributions added new ideas, clarified relationships, and incorporated the ideas of others. Now it is tedious to trace every idea and detail back to its starting point. Therefore, we are satisfied to view Einstein's dramatic entrance as the climax of a setting which had been occupied by other great men playing important rôles. This climax marks the epoch which changed the viewpoint of science and its trend of thought. Wonderful advances have

been made since then, but that may be considered the climactic sunrise, comparable with that of Newton.

The orbit of our neighboring planet, Mercury, does not exactly accord with the computations from Newton's laws. A small movement of the perihelion remained unexplained. Newton assumed that free matter in free space would move in a straight line between two points. It is interesting to note that Einstein's theory accounts very well for the "residual" motion of Mercury's orbit "left over" after Newton's laws were applied. It should be noted that even the geometric space which we inherited from Euclid is not consistent with the new concepts. According to the ideas preceding the present century, a planet like Mercury should describe an ellipse around the sun and it should retrace this identical path each time. Measurements indicate that Mercury proceeds almost exactly over the same path — *but not quite*. Each elliptical path of successive revolutions around the sun is slightly in advance of the preceding one. That is, according to Einstein's general theory of relativity the plane of the orbit of each of the planets is slowly rotating in the direction of the planet's motion, the magnitude of rotation being greatest for the planet nearest the Sun.

Ever since the middle of the nineteenth century it has been known that the elliptical orbit of Mercury turns through an angle of 574 seconds each century, most of which is accounted for by the effects of gravitation of other celestial bodies. However, 43 seconds of arc per century remained unaccounted for and this puzzled scientists. Einstein's law of gravitation or his general theory of relativity showed that Newton's law of attraction was a special case. This new general law scored a great triumph when it exactly accounted for the 43 seconds of rotation of Mercury's orbit per century.

According to the new concepts of Einstein's general theory,

a ray of light should possess something equivalent to mass. If so, it should be deflected slightly from its path toward a large mass when passing near it. For example, according to this theory the light rays from a star when passing close to the Sun should be deflected 1.7 seconds of arc. (See Fig. 8.) If it

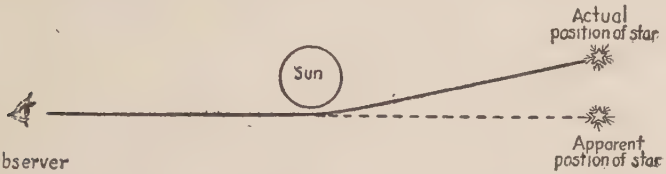


FIG. 8. Illustrating the bending of a beam of light from a star as it passes close to the Sun. According to Einstein's general law of gravitation the beam should be bent 1 3/4 seconds of arc from its path. This is a very minute angle (greatly magnified above); nevertheless, it was measured and Einstein's prediction was verified. Maxwell's electro-magnetic theory of light predicted that radiant energy exerts pressure and also that a beam of light would be deflected (half as much as Einstein's prediction) in passing close to the Sun.

passed the Sun at a greater distance from the surface, the deflection should not be as great A total eclipse of the Sun was to be visible in the southern hemisphere on May 29, 1919. Einstein's general theory appeared in 1915 when Europe was upset by war, but science must grasp its opportunities if possible. It is a great tribute to England that, while engaged in a gigantic struggle of uncertain outcome, two expeditions were equipped and sent to test the validity of the Einstein predictions by photographing stars showing near the edge of the Sun when completely eclipsed. One expedition went to Brazil, the other to Africa. The result was a great triumph for that wonderful philosopher who evolved the general theory of relativity. Other verifications were made in 1922.

The Universe

Einstein and others have continued to extend the new ideas which have revolutionized physics. In fact, one might almost believe that the new concepts have destroyed the physical universe as far as our ability to picture it physically is concerned. Probably a true conception of the world would be more readily achieved if we admitted at the outset that we now have to picture a psychological rather than a physical world. It was long ago recognized that an infinite universe cannot be reconciled with Newton's law of gravitation. If this were true there would be an infinite mass in all directions, with the result that an indeterminate force would attract every celestial body from all directions. A stable system like our solar system could not exist. If we imagine an infinite space, with a finite number of stars, we could well wonder why the celestial bodies did not scatter throughout this infinity. It seems impossible to reconcile with Newton's laws a universe that is infinite and, at first thought, it seems equally difficult to imagine it to be limited. We immediately ask, "Limited by what?"

Einstein assumed the universe to have a finite volume although it was unbounded. Doubtless, the reader, if he has not already deserted, will weaken at this point. However, the circumference of a circle has no end or beginning, but it has a definite length. It is unlimited, but is finite. This is so because it is *curved*. Minkowski, a great mathematican, in 1908 developed a geometric interpretation of the three spatial and one temporal dimensions involved in the special theory of relativity. A knowledge of this would help the reader to understand the new conceptions of the universe, but unfortunately the Minkowski world exists for us only in mathematics which we cannot draw upon here. The Earth's

surface is endless, but definite in area. Continuing thus we find a three-dimensional analogy in spherical space. However, no human being can conceive of spherical space although it is easily represented mathematically. Einstein propounded the idea of a *curvature of the universe*. This is an interesting way of providing for us a *boundless universe which is limited*.

Based on Einstein's theory of gravitation, De Sitter concluded that the average density of matter in the universe is 10^{-26} the density of water. Although we can scarcely conceive the smallness of that number we are not greatly surprised, because of the enormous distances between the celestial bodies of relatively small dimensions.

With this density as a basis, the circumference of the universe is found to be 100 million light-years. A light-year is the distance that light travels in a year at a velocity of 186,000 miles per second. It is equal to 63,000 times the distance from the Earth to the Sun. In other words, the circumference of the universe as determined by De Sitter is 6300 billion (or 6.3 million million) times the distance from the Earth to the Sun.

The total mass of the universe is then found to be 100 billion billion (10^{20}) times the mass of the Sun, or a total of 10^{54} grams.

It follows that the total number of electrons in the universe is 10^{78}.

The human mind cannot conceive such numbers, but this is a matter of training and experience. Many of us now have as definite an idea of a million as we once had of a thousand. Haas [1] gives an excellent example which shows that such numbers can be arrived at quickly. Bacteria propagate by the simple process of subdivision. Suppose we begin with a single bacterium and that it divides into two bacteria in an

[1] " The New Physics," Arthur Haas, 1923.

hour. Each of these now divides into two during the second hour so that we have four at the end of the second hour. Suppose this process could be continued and that each bacterium weighed a billionth of a gram. At the end of 24 hours there would be 16 million bacteria. At the end of the third day there would be 5×10^{21} or 5,000 billion billion bacteria. These would weigh thousands of tons. At the end of the sixth day the mass of bacteria would equal that of the Earth. At the end of a week the mass would equal that of the Sun. At the end of ten days the mass would equal that of the universe. At the end of eleven days the total number of bacteria would equal the total number of electrons in the universe as computed by De Sitter.

These numbers show again the limitations of the human senses and the human mind. They indicate, as many other facts do, that *we* are responsible for the complex picture of Nature. Theoretical physics is liberating Nature from the shackles of the human viewpoint, but unfortunately it still remains complex to those who cannot understand and use that wonderful medium of expression — mathematics.

Our position is described by Pope in his "Essay on Man" thus, —

> "Chaos of thought and passion, all confused;
> Still by himself abused and disabused;
> Created half to rise, and half to fall;
> Great lord of all things, yet a prey to all;
> Sole judge of truth, in endless error hurled;
> The glory, jest and riddle of the world!"
>
> *Pope*

Chapter VIII

THE ELEMENTS OF MATTER

Matter, its distribution in space, the laws governing its movements and the nature of its processes are foundations of the universe. However, the constitution of matter itself is still more foundational, because the fundamental laws and processes of Nature must begin here. Man has striven for centuries to understand matter, but it is only recently that he has been able to peep through the doorways of the structures of molecules and atoms. However, these glimpses have revealed wonderful mechanisms and systematic structures. Perhaps it is more nearly the truth to state that molecules are definite relationships of minute mechanisms. The glimpses that Man has had reveal not immobile structures of passive elements, but a busy world of motion. As might have been expected, simplicity and orderliness prevail. Furthermore, the mechanisms of the atoms of different elements of matter seem to be made up of the same kind of material and of movements. The difference is largely, if not solely, due to different numbers of these individual particles and, consequently, of their simple motions. As our knowledge of the constitution of matter becomes more dependable we find emphasized again the simplicity and unification of Nature. Modern knowledge has shown that chemistry is a subdivision of the science of physics just as optics and electromagnetism are parts of physical science. It is based on physical laws, not upon mysterious principles and affinities of anthropomorphic characteristics. It is concerned with the movements and

relationship of small bodies and with the composition and structure of these bodies. It takes these "bricks of matter" and constructs elements of various properties and from these builds compounds.

Earlier Ideas

Of course, thinking men of all ages conjectured as to the ultimate constitution of matter. We have already been introduced to some of these ideas in a previous chapter. Even in early centuries it was recognized that some matter had different properties from other matter, but as usual those early theories were mystical, incoherent, and highly speculative. For example, air, earth, water, and fire were at one time considered to be the basic "elements" of matter which gave to the latter its properties. A substance which had a different property from another was supposed to have more or less of certain of these supposed "elements"; or, in other words, the latter were present in different proportions in the two substances. Naturally, a primordial universal material was assumed to exist with which different proportions of these four "elements" were associated. This accounted for substances of various properties.

It is not surprising that this theory did not account for many properties of substances. As a consequence of its shortcomings, additional "principles" were annexed. For example, sulphur burned; therefore, the degree of combustibility of a substance was thought to be determined by the amount of sulphur in it. Of course, it is now known that many combustibles contain insufficient amounts of sulphur to affect their burning. Finally, when this insufficiency of sulphur was recognized another principle was devised. It was termed *phlogiston.* According to this idea, combustion resulted in the liberation of this hypothetical phlogiston. Metallic oxides,

such as iron ore, were reduced by burning with charcoal, with the result that the pure metal was obtained along with a residue of carbon oxides and ash. Phlogiston was supposed to leave the charcoal and enter the iron ore and by its combination with the iron oxide make of the latter a metal.

These are examples of the early speculations, destined to give way eventually to the idea of individualism or the atomistic principle which had persisted throughout centuries in one form or another.

The Atomic Theory

A true beginning was made by Boyle (1627–1691) in the explanation of the composition of substances. He was an experimenter, which accounts for the value of his theories, for he obtained data before theorizing. He concluded that substances were *elements* of matter or combinations of them. That is, iron was a single element consisting of small indivisible particles of iron. A compound consisted of ultimate particles of the elements involved. He invented the idea that some elements have an *affinity* for others, the result of which is a marriage of such elements. This was the cause of compounds. He did not attempt to explain affinity, but, on the other hand, he forsook the early fanciful ideas of it.

Lavoisier (1743–1794) established the principle of the indestructibility of matter. This marked a real beginning of modern chemistry. He abandoned the older empirical chemistry and devoted himself to careful measurements of weight in connection with chemical reactions. He shares with Dalton (1766–1844) the honor of establishing fundamental facts of chemistry which made it possible for the first time in history to consider chemistry a science. The idea of molecules and their constituents — atoms — was firmly founded by Dalton

when he propounded the *law of multiple proportions*. From determinations, made by him, and others, of weights of elements entering into compounds, he concluded that certain constant proportions (by weight) were characteristic of any compound. He found that a number could be given to every element so that the quantities of elements in compounds are related as exact multiples of these characteristic numbers. Thus he developed the idea of *relative atomic weights*. These were the numbers he gave to the various elements. Hydrogen, the lightest element, was at first the basis for a system of atomic weights.

This atomic theory established chemistry on a firm foundation. For example, two atoms of hydrogen always combined with one of oxygen to form a molecule of water. The atomic weight of oxygen was considered to be 16 times that of hydrogen so the relative molecular weight was considered to be 18. It is now known that the atomic weight of oxygen is 15.88 in terms of the hydrogen when the latter is assumed to be 1. If oxygen is assumed to have a relative atomic weight of 16, hydrogen has an atomic weight of 1.008. The latter scheme is now in use. At the time Dalton developed his famous law only 30 elements had been discovered. Now about a hundred are known.

Avogadro, in 1811, propounded a law which was also destined to become a fundamental of the molecular theory of matter. According to this law, equal volumes of different gases, under the same pressure and at the same temperature, contain an equal number of molecules. Therefore, the masses of equal volumes under these conditions are proportional to the molecular weights of the gases. Furthermore, the volume of a *gram-molecule* (the number of grams of the gas equal to the number representing its molecular weight) is the same for all gases at equal temperature and pressure. The gram-

molecule is termed a *mole*. The molecular weight is equal to the sum of all the atomic weights of all the atoms combined in the molecule. A mole or gram-molecule of water is approximately 18 grams.

After Dalton established the atomic theory and the definite combination of elements in the formation of compounds, Faraday (1791–1867) revealed the results of *electrolysis*. By passing an electric current through various liquids, he found that the liquid was decomposed in a definite way. The molecules of the liquid divide into components possessing equal and opposite (negative and positive) charges of electricity. These components are termed *ions*. For example, a molecule of water, H_2O, divides into a positive hydrogen ion and a negative oxygen ion. Conduction of electricity through a liquid is merely a movement of these ions. The negative ions gather at the terminal where the electric current enters the liquid and the positive ions at the one where the current leaves. Each atom of the hydrogen is now known to have associated with it a definite unit charge so that each oxygen atom has twice this charge of opposite sign. A general statement may be made to the effect that the charge of any ion is equal to this unit charge or an exact multiple thereof, depending upon the chemical valency of the ion. Valence is the ability of atoms to combine, in terms of the ability of hydrogen to combine, the valency of hydrogen being unity.

Faraday found that the amount of the liquid decomposed by the electric current is proportional to the current. The magnitude of the unit charge or quantum of electricity is now known to a high degree of accuracy. Thus, it is seen that electrochemistry contributed much to our early knowledge of the atomic theory of matter.

Why atoms of elements combine always in exactly the same manner to form a given compound, or indeed why they com-

bine at all, was a complete mystery until recently. Even now all the details are not known. The term *affinity* as first used implied certain mystical reasons. Atoms were given human traits. Some liked each other; others did not. Very fanciful ideas were propounded. Atoms and molecules were given various shapes. Some were prickly, others were not so viciously armed. Newton naturally applied his law of attraction. However, explanations based upon electrical phenomena gradually arose and present theory universally involves an electrical cause, as is seen in later chapters.

Atoms and Molecules

The existence of atoms has been thoroughly established even though nobody has ever seen one. They are so small that about a hundred million could be marshalled into a single file an inch long. If we directed a microscope at this file we could not distinguish an area less than about 200 atoms in diameter. In other words, the smallest area that we can now detect with a microscope would be covered by a single layer of atoms aggregating about 30,000 atoms. (See Figs. 1 and 2.) However, the scientist has many indirect methods at his disposal by means of which he has become quite intimately acquainted with the atom and even with its structure. But he is more handicapped than a blind man usually is, for he not only *cannot see,* but he cannot feel the atom. He must draw upon his imagination for constructing the atom out of his experiences with its behavior and properties. For these reasons, the ultimate shape and structure are not known definitely, but for the present purpose the reader may safely picture atoms as being approximately spherical. In this chapter we will be concerned chiefly with the atom as a whole and not with its structure.

Science has revealed 92 elements differing distinctly in properties so that we now say that there are 92 different kinds or families of atoms. The members of each family are exactly alike with certain possible exceptions which need not concern us here. The atoms of different kinds differ in size and vary greatly in weight. For example, 236 atoms of hydrogen weigh the same as one atom of uranium, but each atom of hydrogen is probably two-fifths the size of a uranium atom.

The properties of atoms of different families differ very widely so that it is difficult to believe that they can all be reduced to the same fundamental materials and forces. Still this seems to be the promising outlook at present. On the other hand, there are similarities between certain atoms which suggest that they are related in some manner. We might think of these as analogous to a race and their similarities are racial characteristics. We may then carry the analogy further, because, like races of men, the atoms show common characteristics which are suggestive of a common origin.

Atoms do not ordinarily exist singly. The married state apparently is the natural one. For example, in pure hydrogen we do not have single atoms, but groups consisting of two atoms each. These groups, each expressed as H_2, are molecules of hydrogen. When atoms of only one family are present in a substance this is termed an *element*. Thus "pure" hydrogen, iron, and about a hundred other pure substances are elements. If two or more families of atoms are represented in the molecules of the substance, the latter is termed a compound. Water (H_2O) is a compound consisting of molecules each of which is made up of two atoms of hydrogen and one of oxygen. Cane sugar ($C_{12}H_{22}O_{11}$) consists of molecules each of which is made up of 12 atoms of carbon, 22 atoms of hydrogen and 11 atoms of oxygen. On close examination it is seen that the hydrogen and the oxygen atoms are combined in

exactly the same proportion as they are in water. However, if we mix carbon and water in the proportion (by weight) of 12 parts of carbon and 11 parts of water we do not get sugar, but an uninviting liquid consisting of carbon particles suspended in water. In fact, if permitted to stand undisturbed the carbon settles to the bottom leaving clear water above it.

This illustrates the importance of what we term *chemical combination* as compared with a mere physical mixture. It also suggests that the manner in which the molecules of a substance are constructed of the bricks (atoms) of matter, is what gives one substance distinctly different properties from another substance even though the two substances contain the same kinds of atoms and even in the same proportions.

Another aspect is well illustrated by the compound, sodium chloride (Na Cl), which is common salt, almost indispensable to civilized peoples. It makes foods more palatable and has many useful properties. Still its molecules are each made up of one atom each of two elements which are rather vicious. Sodium is a metal that rapidly oxidizes (burns up) in the presence of free oxygen or water. Place a piece of sodium in water and it sizzles very actively as it combines with the oxygen and part of the hydrogen. If it is placed on the tongue or held in a moist hand, a "burn" is the result. Chlorine is a heavy yellowish gas which is very "corrosive" and poisonous. The combination of these two very active elements makes molecules which are relatively docile. But this is not always true, for in many cases quiet unassuming elements form molecules of very active properties. One might carry our human analogy further and reflect upon molecules as the married state of atoms.

As already intimated there are substances which have different properties although their molecules are made up of the

same number of the same elements. Doubtless, we can conceive combinations of the same number of pieces of different materials which would produce substances of different properties. This emphasizes the importance of structure. Two chemical compounds having the same proportions of elements, but differing in property, are termed isomers. They are common among the so-called hydro-carbons (compounds of hydrogen, oxygen and carbon). For example, about two dozen compounds are known whose molecules consist of 6 atoms of hydrogen, 3 of oxygen, and 4 of carbon. These isomers are proof that the properties of substances depend to some extent upon the structure of the molecule; that is, upon the actual arrangement of the atoms in the molecule.

It has been stated that atoms do not ordinarily exist singly; that is, even in elements the atoms are generally combined into molecules. However, we are not surprised to find exceptions in such a complexity of ties of family and of races. Mercury vapor seems to consist of single atoms uncombined with each other. Hydrogen gas consists of molecules of two atoms each. Some elements consist of molecules built up of several individual atoms. Sulphur exists in different forms and also phosphorus. It seems possible that these different forms of the same element are accounted for solely by different numbers of atoms in the respective molecules. Similarly, graphite, the diamond, and charcoal, if pure, consist of nothing (as far as is known) but carbon. Perhaps their respective molecules consist of different numbers or arrangements of carbon atoms.

Whether a substance is a solid, a liquid, or a gas apparently depends upon the arrangement and perhaps the shape of the molecules. They are fitted relatively close together in a solid and tend to remain so. There is a degree of orderliness which accounts for the permanency of shape. In a liquid this order-

liness does not exist although the molecules are still limited in their movements by molecular "spheres of influence." The gaseous state represents a complete disappearance of order and attraction of one molecule for another. There is some evidence that the forms and structures of molecules have something to do with the forms of crystals. However, the study of crystals by means of Röntgen rays seems to indicate that the atom is of primary importance in the structure of crystals. Certainly the most casual observation of crystals suggests that the acme of orderliness of molecules and atoms must be attributed to them.

Although exact knowledge of the size of atoms is far from complete there is some evidence that the size increases slightly with increase in atomic weight. On the basis of this evidence we could arrange the elements in a row of increasing atomic weights with hydrogen (atomic weight = 1.008) at one end and uranium (atomic weight = 240) at the other. Assuming for the present that the atoms are spherical we may begin our model of the relative size of the hydrogen atom with a sphere 10 inches in diameter. The relative size of the uranium atom at the other end of the row would be represented by a sphere about 25 inches in diameter. If we represented the relative weight of the hydrogen atom by making the 10–inch sphere of white pine, the 25-inch sphere, in order to represent the relative weight (as well as the relative size) of the uranium atom, would have to be made of something somewhat heavier than lead.

Chemical Action

As we watch the flames of a bonfire we are not conscious of the relatively simple physical phenomenon which is taking place. The flames roar, the material crackles, smoke rises, and the material is consumed. That is the picture which our

eyes see. It is a long step from this picture to the molecular one which we can see only in our imagination. Molecules of oxygen in the air are broken into the two atoms of oxygen of which they are composed. The organic compounds of the wood, consisting of carbon, hydrogen, nitrogen and oxygen, are broken up more or less into atoms. A carbon atom unites with two of oxygen and a gas, carbon dioxide, is formed. In some cases only one atom of oxygen is united with one carbon atom and carbon monoxide (a gas) results. Hydrogen atoms unite with oxygen to form water which escapes vaporized by the heat. Where does the heat come from? It is a product of the chemical reaction. There is potential energy in molecules of substances. When there is a change in the molecular structures there is a change in the energy relationships. If potential energy is lost, this energy may manifest itself by raising the temperature of the substances involved and also of the surroundings. In such a chemical action as a bonfire perhaps there are hundreds of different reactions taking place, of which the foregoing are only simple examples.

Everywhere about us chemical action is going on. Iron "rusts" because iron atoms combine with the oxygen of water forming iron oxide which we term "rust." Acid eats metals, clothing, and many substances. The action is merely a physical one — an interchange of atoms between the molecules of compounds involved. The explosions in the cylinders of the automobile engine are interchanges of atoms between molecules of different kinds. The resulting products are largely gases which desire a greater volume than the original products. Hence the pistons move and we joy-ride. Little do we appreciate that the whole process can be reduced to relatively simple interchanges of physical realities — atoms.

The Elements

Modern theory and knowledge indicate that there are only 92 different chemical elements. Radio-active elements such as radium and uranium give birth to apparently distinct elements and these in turn do likewise. Some of these products are very unstable and their properties and atomic weights are not well known. Therefore, much doubt exists in regard to them. Certainly it is well proved that some elements are born from others. The basic ingredients of all atoms appear to be the same. Combining these two facts gives rise to the hope that elements are the result of a simple evolution from one parent. Of course, there is a possibility that they are generally actually constructed from the same primordial material and elementary mechanism.

After a sufficient number of elements were discovered, a close study of their properties revealed some "family" resemblances. As a consequence, Mendeleeff and others arranged the elements in a rectangular setting according to atomic weight. Those falling in a row were found to have somewhat similar properties. This is termed the *periodic system*. (See table.) Some gaps were left in this arrangement but most of these "missing" elements were eventually discovered. Here again we find orderliness and system, for in this series of elements arranged in the order of increasing atomic weight, certain properties recur periodically. The regularity was such that Mendeleeff actually predicted the properties of several "unknown" elements from the properties of known elements, from their position or "periodicity" in this apparently empirical system.

A table of elements is presented herewith, including the atomic numbers, atomic weights, symbols, chief characteristics and the approximate date discovered. The significance

of atomic numbers is explained later. Some elements have been known to exist so long that the date of discovery is unknown. These are designated in the date column by the word "early."

In another table the elements are arranged in what may be termed the *periodic table*. In the sixth horizontal row the rare-earths are merely indicated in their proper place. The elements are designated by their usual symbols and their atomic numbers. It is seen that there are eight groups, each of which include elements of the same *chemical valency*. An atom of an element combines with as many atoms of chlorine (Cl), for example, as indicated by the atom's group number (Roman numerals). Conversely, an atom of Group VII combines with one hydrogen atom; an atom of Group VI with two hydrogen atoms; and so on. Period 1 consists of the elements, hydrogen and helium; Periods 2 and 3 consist of eight elements each; Periods 4 and 5 consist of 18 elements each; Period 6 consists of 32 elements; Period 7 seems to stop at uranium.

Elements belonging to the same group (Roman numerals) exhibit similar physical properties as well as possess the same chemical valency. From the faith that science has in this periodic table it may be safely predicted that elements indicated by atomic numbers 43, 61, 75, 85, and 87 actually exist, but have not been discovered. Furthermore, the elements, 43 and 75, are quite likely to resemble manganese; 61 is likely to be a rare-earth element ; 85 a halogen; and 87 an alkali metal. It will be noted that there are two rows in some Periods and that the elements in these Periods are arranged in two vertical rows for each group. This is a refinement which is found satisfactory.

KNOWN ELEMENTS

Atomic Number	Element	Symbol	Atomic Weight	Character	Date of Discovery
1	Hydrogen	H	1.008	Active gas	1766
2	*Helium	He	4.00	Inert gas	1868
3	Lithium	Li	6.94	Metal	1817
4	Beryllium	Be	9.1	Metal	1828
5	Boron	B	11.0	Non-metal	1808
6	Carbon	C	12.005	Non-metal	Early
7	Nitrogen	N	14.01	Inert gas	1772
8	Oxygen	O	16.00	Active gas	1774
9	Fluorine	F	19.0	Active gas	1810
10	*Neon	Ne	20.2	Inert gas	1898
11	Sodium	Na	23.00	Metal	1807
12	Magnesium	Mg	24.32	Metal	1808
13	Aluminium	Al	27.1	Metal	1828
14	Silicon	Si	28.3	Semi-metallic	1823
15	Phosphorus	P	31.04	Non-metal	1738
16	Sulphur	S	32.06	Non-metal	Early
17	Chlorine	Cl	35.46	Active gas	1810
18	*Argon	A	39.88	Inert gas	1894
19	Potassium	K	39.10	Metal	1807
20	Calcium	Ca	40.07	Earth	1808
21	Scandium	Sc	44.1	Metal	1879
22	Titanium	Ti	48.1	Metal	1795
23	Vanadium	V	51.0	Metal	1801
24	Chromium	Cr	52.0	Metal	1797
25	Manganese	Mn	54.93	Metal	1774
26	Iron	Fe	55.84	Metal	Early
27	Cobalt	Co	58.97	Metal	1733
28	Nickel	Ni	58.68	Metal	1751
29	Copper	Cu	63.57	Metal	Early
30	Zinc	Zn	65.37	Metal	1520
31	Gallium	Ga	69.9	Metal	1875
32	Germanium	Ge	72.5	Metallic	1886
33	Arsenic	As	74.96	Semi-metallic	1649
34	Selenium	Se	79.2	Solid	1817
35	Bromine	Br	79.92	Liquid	1826
36	*Krypton	Kr	82.92	Inert gas	1897
37	Rubidium	Rb	85.45	Metal	1868
38	Strontium	Sr	87.63	Metal	1808
39	Yttrium	Y	88.7	Metal	1823
40	Zirconium	Zr	90.6	Metal	1824
41	Niobium	Nb	93.5	Metal	1846
42	Molybdenum	Mo	96.0	Metal	1782
43	.....	...	....	.....	....
44	Ruthenium	Ru	101.7	Metal	1844
45	Rhodium	Rh	102.9	Metal	1804
46	Palladium	Pd	106.7	Metal	1803

Atomic Number	Element	Symbol	Atomic Weight	Character	Date of Discovery
47	Silver	Ag	107.88	Metal	Early
48	Cadmium	Cd	112.40	Metal	1817
49	Indium	In	114.8	Metal	1863
50	Tin	Sn	118.7	Metal	Early
51	Antimony	Sb	120.2	Metal	1450
52	Tellurium	Te	127.5	Solid	1782
53	Iodine	I	126.92	Solid	1811
54	*Xenon	Xe	130.2	Inert gas	1898
55	Caesium	Cs	132.81	Metal	1860
56	Barium	Ba	137.37	Metal	1808
57	Lanthanum	La	139.0	Metal	1841
58	Cerium	Ce	140.25	Rare-earth metal	1801
59	Praseodymium	Pr	140.9	Rare-earth metal	1885
60	Neodymium	Nd	144.3	Rare-earth metal	1885
61	.....	...	.....	.....	....
62	Samarium	Sa	150.4	Rare-earth metal	1879
63	Europium	Eu	152.0	Rare-earth metal	1901
64	Gadolinium	Gd	157.3	Rare-earth metal	1886
65	Terbium	Tb	159.2	Rare-earth metal	1843
66	Dysprosium	Dy	162.5	Rare-earth metal	1907
67	Holmium	Ho	163.5	Rare-earth metal	1886
68	Erbium	Er	167.7	Rare-earth metal	1843
69	Thulium	Tm	168.5	Rare-earth metal	1879
70	Ytterbium	Yb	173.5	Rare-earth metal	1878
71	Lutecium	Lu	175.0	Rare-earth metal	1908
72	Hafnium	Hf	.....	.....	....
73	Tantalum	Ta	181.5	Metal	1802
74	Tungsten	W	184.0	Metal	1783
75	.....	...	.....	.....	....
76	Osmium	Os	190.9	Metal	1804
77	Iridium	Ir	193.1	Metal	1804
78	Platinum	Pt	195.2	Metal	1500
79	Gold	Au	197.2	Metal	Early
80	Mercury	Hg	200.6	Metal	300 B.C.
81	Thallium	Tl	204.0	Metal	1861
82	Lead	Pb	207.20	Metal	Early
83	Bismuth	Bi	208.0	Metal	1450
84	Polonium	Po	210.0	.....	....
85	.....	...	.....	.....	....
86	*Niton	Nt	222.4	Inert gas	1900
87	.....	...	....	.....	....
88	Radium	Ra	226.0	Metal	1898
89	Actinium	Ac	227	.....	....
90	Thorium	Th	232.4	Rare-earth metal	1828
91	Uranium X_2	UX_2	234	.....	....
92	Uranium	U	238.2	Metal	1780

*The transition from one Period to the next in the periodic system.

PERIODIC TABLE OF ELEMENTS

ELEMENTS IN ANY VERTICAL COLUMN HAVE SIMILAR PROPERTIES
HORIZONTAL ROWS ARE TERMED "PERIODS"
ATOMIC NUMBERS PRECEDE THE SYMBOLS

	I	II	III	IV	V	VI	VII	VIII	
1	1H	.....	.....	.....	.....	.....	.....	.....	2He
2	3Li	4Be	5B	6C	7N	8O	9F	.....	10Ne
3	11Na	12Mg	13Al	14Si	15P	16S	17Cl	.....	18A
4	19K 29Cu	20Ca 30Zn	21Sc 31Ga	22Ti 32Ge	23V 33As	24Cr 34Se	25Mn 35Br	26Fe 27Co 28Ni	36Kr
5	37Rb 47Ag	38Sr 48Cd	39Y 49In	40Zr 50Sn	41Nb 51Sb	42Mo 52Te	43 – 53I	44Ru 45Rh 46Pd	54Xe
6	55Cs 79Au	56Ba 80Hg	57–71 rare-earths 81Tl	72Hf 82Pb	73Ta 83Bi	74W 84Po	75 – 85 –	76Os 77Ir 78Pt	(Em) 86Nt
7	87 –	88Ra	89Ac	90Th	91UX2	92U			

Isotopes

As we look over the atomic weights in the list of elements we note that some of them are whole numbers and many of them are nearly so. Perhaps we conclude that, in general, they are too nearly whole numbers to be merely accidental. Perhaps we wonder why Nature built up a series of elements out of "bricks" of odd sizes. Such thoughts came to Prout, in 1813, and the result was that he developed an hypothesis in which hydrogen atoms were the "bricks" of which the atoms were built. He experienced difficulty in explaining why the atomic weights of many of the elements were not whole numbers and his idea did not win much favor. However, three quarters of a century later the idea was revived by a suggestion from Crookes. This suggestion was to the effect that possibly an atomic weight as we determine it is really the average of a large number of atoms. For example, the atomic weight of chlorine, 35.46, might be the average of a definite mixture of constant proportions of chlorine atoms of two different atomic weights, 35 and 37 respectively. Aston has actually proved this to be true; that is, that a proportion of about three atoms of atomic weight 35 to about one of atomic weight 37 accounted for the atomic weight of chlorine. These two constituents have chemical properties exactly like chlorine and they are termed *isotopes*. They are readily explained by the newer theories of the structure of the atom which are discussed in other chapters.

One of the most brilliant achievements of modern science has been in the discovery of isotopes and the determination of the proportions of two or more of them of atomic weights in whole numbers which are combined to make up the "average" atomic weight of an element which usually is not a whole number. Why two atoms of chlorine, for example,

having different whole-number atomic weights are always found to exist together in definite proportions is a matter which cannot be discussed with profit at this point. The "pure" elements, each consisting solely of atoms of identical mass and structure, are hydrogen, helium, carbon, nitrogen, oxygen, fluorine, phosphorus, sulphur, and arsenic. In this connection it is of interest to refer to the table of elements. Some of the elements which are mixtures of atoms differing in mass, but possessing identical chemical properties (isotopes), are give herewith. Other isotopes are to be found in the radioactive series presented in a later chapter.

Some Isotopic Elements

Element	Atomic Weight	Number of isotopes	Atomic weights of isotopes
Neon	20.2	2	20, 22
Silicon	28.3	2 or 3	28, 29, 30 (?)
Argon	39.88	2	36, 40
Chlorine	35.46	2	35, 37
Bromine	79.92	2	79, 81
Krypton	82.92	5 or 6	78 (?), 80, 82, 83, 84, 86
Xenon	130.2	5 (?)	128, 130, 131, 133, 135
Mercury	200.6	5 or more	202, 204, and some between 197 and 200

The work on isotopism is far from complete, but the outlook is promising for finding that all elements consist of atoms which possess whole-number atomic weights. Thus again we are encouraged to continue our faith in the simplicity of the structure and processes of the physical world. In the list of elements the reader has noted that atomic numbers are whole numbers. These indicate the number of certain "things" in the atoms. Here again simplicity is evident. The atomic number has already played an important part in unravelling the skein of matter which to our limited senses has been so tangled. Some of these aspects of atomic structure are discussed later.

Atomic Numbers

The list of elements, as presented herewith, is generally arranged in the order of increasing atomic weight. In such a list it is seen that there is no uniformity in the differences in the atomic weights which begin with hydrogen at 1.008 and end with uranium at 238.2. In fact, the steps are so irregular that we could remove one of the atomic weights here and there without noticing any distinct gap. This non-uniformity is not compatible with a simple natural scheme, with a simple relation between the elements, or with the idea that elements are constructed of the same "bricks" but of different number and arrangement.

One of the greatest contributions of experimental physics to theoretical physics in recent years was made by Moseley (1888–1915) who, in 1913, erased this irregularity by showing that the series of numbers from 1 to 92 could be applied with great significance to the series of elements respectively from hydrogen to uranium as shown in the table of elements. Moseley in his lamentably short life-time discovered this *natural series of elements* which has since been a very vital factor in the development of theories of atomic structure.

It will be recalled that for years the nature of Röntgen rays (X-rays) was a mystery to scientists. All devices, such as the glass prism or diffraction grating, failed to disperse them into their various wavelengths (for they were suspected of being electromagnetic waves) because of their extremely short wavelength. Gratings could not be ruled fine enough to do this work by the usual optical method of diffraction. Laue had a happy inspiration. Why not use crystals which are known to have molecules arranged in perfect regularity?

These molecules should diffract Röntgen rays as satisfactorily as ruled gratings produce the spectrum of light. Bragg adopted this idea with great success.

When Röntgen rays strike a body the latter emits secondary Röntgen rays whose frequencies or wavelengths are characteristic of the elements of the substance. Moseley studied the characteristic Röntgen radiation from many elements and discovered that the elements can be arranged in a *natural series*. The various spectra of these characteristic rays show a displacement of the individual spectral lines (wave-frequencies) of great regularity from element to element. The uniformity is so great that the gap due to a missing element is perfectly obvious, which is not true of atomic weights. The sequence of the elements in this natural series is identical with that of increasing atomic weight with a few exceptions, such as argon, cobalt, tellurium and thorium, as seen in the list of elements. The natural series of elements are given numbers from 1 to 92 as already stated. These numbers are termed *atomic numbers*. There are five gaps in this natural series corresponding to atomic numbers 43, 61, 75, 85 and 87. Therefore, it appears that there are only five elements yet to be discovered between hydrogen and uranium. Whether or not any elements of greater atomic number or atomic weight than uranium exist, is a question that cannot be answered with finality at the present time.

As seen in Chapter X, when an alpha particle (helium atom) is expelled from a radioactive atom the atomic weight of the atom decreases 4 units. This is because the atomic weight of the helium atom is 4. The expulsion of an alpha particle reduces the atomic number by 2 and, therefore, causes the element to shift two spaces to the left in the periodic table. The emission of an electron does not appreciably affect the

atomic weight, but displaces the element one space to the right. It will be noted that atomic numbers are used in the periodic table instead of atomic weights as has been the custom until recently. The importance of these various facts is revealed further in other chapters.

Chapter IX

THE ELECTRON THEORY

By applying the principle of individualism to matter, atoms and combinations of them into molecules were invented by the imagination. The atomic and molecular theories of matter have been amply verified by much experimental data. The result is a firm foundation for the science of chemistry and of the structure of matter. This view of matter had become firmly established about the time that the electromagnetic theory of light (and of radiation in general) was developed by Maxwell. Then, for the first time, matter was known to emit electromagnetic waves. Naturally, this led to investigations designed to reveal the mechanisms of molecules or of atoms which were the source of electromagnetic waves such as light-waves.

In looking back over the data available, as is a natural course when a radically new discovery is made or theory is presented, scientists found many data which indicated that electricity is in some way bound up in matter. Faraday's discoveries of the process of electrolysis in 1833 revealed the fact that the portions of a molecule of a liquid through which electric current was passed, had definite charges of electricity associated with them. These charged portions of the molecules were termed *ions* from the Greek for *traveler*. These ions traveled through the liquid to the terminals of opposite polarity. That is, the positive ions assembled at the negative terminal and the negative ones at the positive terminal. Thus electrolysis reveals the fact that there is such a thing as

an elementary charge of electricity because the charges on the ions were either equal to this elementary charge or were exact multiples of it.

The Magnitude of the Electron

If water is subjected to electrolysis by merely passing a current through it the molecule of water (H_2O) is broken up and the hydrogen and the oxygen atoms are said to be *ionized.* This is because electric charges are associated with them. The magnitude of the elementary charge is now known accurately.

Before the science of electricity could progress, certain units of measurement were necessary. Therefore, the unit charge, or *absolute electrostatic unit of electricity,* was defined as that quantity of electricity which exerts a force of one dyne on an equal quantity of electricty at a distance of one centimeter. (A dyne is about equal to two millionths of a pound.) In terms of this definition, the fundamental charge, which we will term the *electron,* is equal to 4.77×10^{-10} electrostatic unit. This is 0.477 billionth of an electrostatic unit.

Another way of defining the electron is in terms of the practical unit of quantity of electricity — *the coulomb* — which is established on the basis of electrolysis of silver nitrate, but the details need not be given here. A coulomb is the quantity of electricity which is represented by an ampere flowing for one second. It is seen that this unit is not large because an ordinary dry-cell short-circuited for a second will yield many coulombs. However, the minuteness of the electron is demonstrated by the fact that this elementary charge of electricity is equal to 1.59×10^{-19} coulombs. In common language it is about 16 hundredths of a billionth of a billionth of a cou-

lomb. In other words, when an ampere of electric current flows for one sixth of a second the quantity of electricity is equivalent to the passage of a billion billion electrons. Let us illustrate this by means of an ordinary 15-watt tungsten-filament lamp. Each second the quantity of electricity flowing through any cross-section of the filament is equal to about one billion billion or one million million million electrons.

Two hydrogen ions, each possessing a charge equal to one electron, will be attracted by their force of gravitation depending upon their masses and their distance apart. This can be computed readily from their known masses. The mass of each is equivalent to 1.6×10^{-24} gram. They will repel each other by virtue of the electric charge — the electron — on each. This repulsion can be computed from the data presented in the preceding paragraphs. It is found that the electric force is about 10^{36} times greater than the gravitational force.

A Moving Electric Charge

It will be recalled that the electromagnetic theory of light was one of those epochs in scientific progress which radically altered the trend of science. It was responsible for great activity in the study of electrical phenomena in connection with matter. This theory was the product of mathematical physics and many points needed proof or disproof of experimental data. In 1876 Rowland found that a charged body in motion exhibits the same properties as an electric current flowing in a conductor. His experiment with a large charged body was a model of the moving electron which is now known to be a vital factor in the atom and in many physical phenomena. This moving charged body represents a current. Around it a magnetic field is produced just as a magnetic field exists around a wire in which an electric current is flowing.

From the data of this experiment and from other data, J. J. Thomson, in 1881, concluded that an electric charge exhibits a property equivalent to mass (inertia) which had been associated with all matter. Inasmuch as the electron consists (as far as we know now) of nothing excepting electricity, if it possessed mass, it must be electromagnetic mass. When an electron is at rest, it has merely some potential energy, but when it is moving it has in addition to this some energy corresponding to the work done in setting it in motion. When it is moving it has a magnetic field around it like that around a current flowing in a wire. This magnetic field represents energy. Where does this electromagnetic energy come from when the electron moves and where does it go to when the electron stops? Obviously energy cannot create itself. It comes from the work done to set it in motion. It will be recalled that this is the way Newton arrived at the conclusion that matter possessed mass. Therefore, by a similar reasoning Thomson concluded that the electron had something equivalent to mass and he termed this *electromagnetic mass*.

This was a new and far-reaching conception, but as is seen from the foregoing, it was arrived at through a simple parallel to Newton's procedure with matter. It merely required imagination to apply old principles which had been developed for so-called matter to the new " matter " such as the electron which is an electric charge quite without matter in the older sense of the term. It should be obvious that electromagnetic mass, although being due to the moving electron, is associated more with the space around the electron than with the electron itself. Thomson concluded that a satisfactory way of describing the electromagnetic mass of an electric charge was to consider that each unit of space possessed a certain amount of potential energy. The potential energy of this unit space is proportional to the electromagnetic

mass of the particle. Kinetic energy of a moving body of matter is equal to $\frac{1}{2}$ (mass) times (velocity).^{2} The kinetic energy of a moving electric charge is represented by the potential energy in the space around it because it carries this "field" with it as it moves. It follows from this that the potential energy in any volume of space equals $\frac{1}{2}$ (electromagnetic mass in this space) times (velocity of light).^{2}

From the mathematical treatment of electromagnetic mass it is found that practically all this mass is in the space very close to the electron. The electromagnetic mass is also shown to increase with increase in velocity of the moving charge or electron. This has since been proved by experiments with electrons. It appears that the mass becomes infinite when the velocity equals that of light. Certainly a part of the mass of ordinary matter is electromagnetic; that is, due to the movement of the electrons in the body, which necessarily move with the body. This point is discussed in relation to atomic structure.

Associating mass and potential energy is common in physics. For example, light-waves represent both kinetic and potential energy. This is readily shown by the mathematical equation which Maxwell and others developed for representing electromagnetic phenomena. Therefore, light should exert a pressure when it falls on a body. That it does has been amply proved by E. F. Nichols and others. It is interesting to note that a definite mass is associated with a definite amount of potential energy, whether that energy is due to a charge of electricity or to electromagnetic radiation (light) travelling through space as its great velocity. (See Figs. 4, 5 and 8.)

The Electron Theory

It has been seen that mass became associated with an electric charge or electron. To a moving charge of electricity

laws of mechanics are now as readily applicable as laws of electricity. A relationship of wonderful possibilities had been revealed. Again science was ready for a great generalization which united electrical phenomena and mechanics. Maxwell's theory needed revision as a result of the work of J. J. Thomson and others, and H. A. Lorentz accomplished this by propounding the electron theory. The Maxwell theory had served very well for a long time, not only in explaining the experimental data available, but also more marvelously by predicting much that was later confirmed by experiment. However, no theory can be expected to prophesy correctly forever or to anticipate all the data that are to be obtained. The discovery of the electron, the revelation of some of its properties, and the idea of electromagnetic mass opened up new vistas which even Maxwell's imagination could not have pictured.

Maxwell in developing the electromagnetic theory dealt with conductors and non-conductors of electricity which had definite electric properties. He also required a medium throughout space for carrying light-waves, so he utilized the hypothetical ether. Even though he connected electrical phenomena with matter, he did not deal with the structure of matter. He had no picture of electrons moving about in matter and in its atoms. Lorentz built upon the foundations of Maxwell's theory. Perhaps it would be better to consider that Lorentz to some extent explained these foundations and gave us a picture of a sub-foundation. He began with two primary concepts. He needed a universal medium throughout space so he also adopted the ether, but he insisted that it be stationary always. He did not deal with matter in the old way. Predecessors considered a glass rod or a copper wire to have certain properties. Lorentz considered such so-called material bodies to consist of electrons grouped in definite

arrangements. Conductors and non-conductors of electricity were assumed to differ only in the arrangement of electrons in the groups. As is often the case with a new theory, this one was not founded entirely on known facts. Furthermore, Lorentz used the medium of mathematics to represent his theory exactly. This is noteworthy of all great theories which generalize and unify. Maxwell's and Lorentz's mathematical equations are both stated in terms of electromagnetic forces. These are qualities whose changes can be detected by physical instruments. However, Maxwell emphasized the matter as such, while Lorentz directed his attention to the electric charges in the matter.

The success of the electron theory is exemplified by its explanation of the phenomena of light-waves. It will be recalled that Newton discovered that light-waves of different periodicity (frequency) or wavelength were bent (refracted) different amounts by a glass prism. This and other factors in the wave-theory of light caused great difficulty in reconciling the required properties of the ether with the theory of elasticity of matter. It will be recalled that Maxwell's theory experienced this difficulty, but it explained many facts so well that certain unreconciled details were gradually relegated to the background. Lorentz pictured the source of these electromagnetic light-waves of various wavelengths by assuming unit electric charges (electrons) in the atoms moving in such a manner as to emit periodic radiation. He assumed these electric charges to be actual realities which possessed something equivalent to mass (inertia). Mechanical processes, such as revolution around a center, were responsible for periodicity. These revolving charges were responsible for light-waves, but the actual mechanism does not enter into Lorentz's electron theory. However, he was very successful in picturing a mechanism quite free from assumptions which unduly

strained credulity. This cannot be said of previous theories. It should be noted that Huygen's wave-theory was not completely abandoned by Maxwell. Likewise Maxwell's was not abandoned by Lorentz. In both cases it may be said that the new theory was an extension of the old. (See Fig. 9.)

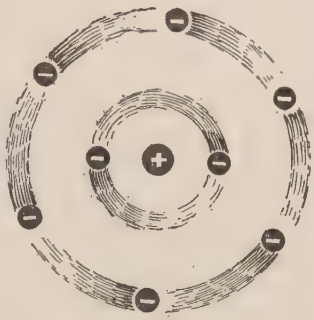


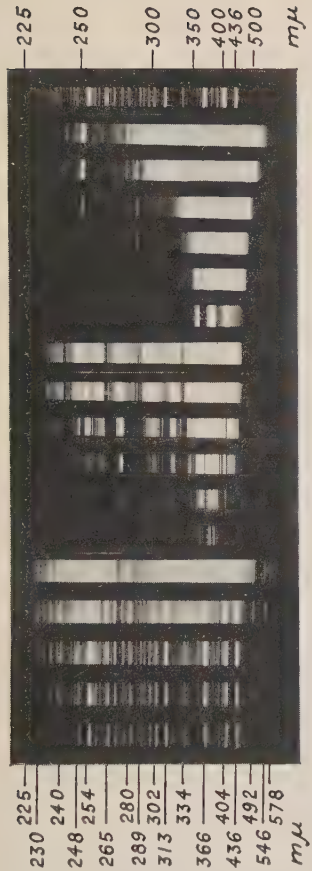
FIG. 9. This is merely an approximate picture of the atom as it is conceived by some. The positive nucleus consists of protons with which some electrons are closely associated. Other electrons revolve around this nucleus in the outer portion of the atom. Changes in the number and arrangement of electrons seem to be involved in chemical changes. Alteration in the nucleus seems to result in different properties of the atom — different elements.

Maxwell's theory did not explain how light and radiant energy in general were produced. Lorentz began at the source. He attributed to electrons in motion the same properties as had been exhibited by a large charge in motion. If a charge is stationary, only an electrostatic (electric) field exists around it. If it moves with a uniform velocity in a straight line, a magnetic field is produced, because the electron in motion is really an electric current. Being in motion, both the electric and the magnetic fields move with it; however, they are otherwise fixed or unvarying. When a change in motion, such as an acceleration, takes place there is a change in the electromagnetic field; that is, an electromagnetic disturbance — a wave — is produced. If an electron revolves with a uniform velocity in an orbit such as a circle it is always changing in direction. A force is holding it in its orbit like the Earth holds the Moon. It is prevented from following its natural tendency "to move in a straight line forever" as Newton's law so accurately postulates. Force

is equal to mass times acceleration. For any given condition the force and mass associated with the electron are constant; therefore, with an electron moving in a circular orbit acceleration is associated. (This is the same for the Moon.) Acceleration means that electromagnetic disturbances are produced and they will be periodic because of the uniformity of the revolution of the electron. This may be clearer if we view the plane of the electron's orbit edgewise. The electron will appear to move to and fro along a diameter of the orbit. This is a source of periodic light-waves. Thus we can picture spherical waves proceeding outward from an electron revolving in its closed orbit and the velocity of any point on the wavefront is that of light.

By way of preparing the reader for further developments in later chapters it is pointed out that nothing in this theory requires a *continuous* wave-front. We may think of radial *lines* of disturbance. These lines may be considered to be radii of a sphere which for any wave is expanding uniformly in all directions in space with the velocity of light. Light-waves may be pictured as a series of concentric spheres, with surfaces one wavelength apart, expanding at an enormous velocity. If these radial lines of disturbance are infinite in number the wave-front is continuous like the surface of a sphere.

Thomson introduced the idea that an electric charge does not produce a continuous field around it. He started out with the assumption that an electron possessed a finite number of *tubes of force* extending radially from it. He attached this idea of the electron with the "electric whiskers" to the Lorentz electron theory. This added a detail to the picture without altering the primary conclusions of the theory. Later Planck in 1900 propounded the quantum theory of radiation in which radiation, such as light, is considered to consist of



	Relative Exposure
Quartz Mercury Arc	
Carbon Arc	32
" "	16
" "	8
" "	4
" "	2
" "	1
Iron Arc	32
" "	16
" "	8
" "	4
" "	2
" "	1
Quartz Mercury Arc	16
" " "	8
" " "	4
" " "	2
" " "	1

FIG. 10. The characteristic line-spectra of carbon, iron and mercury respectively, as emitted from the electric arc between electrodes of these materials. Wavelengths of some of the prominent lines are shown in millionths of a millimeter (mμ). The limit of the visible spectrum is at about 390 mμ. The wavelengths shorter than this are in the ultraviolet region. Various relative photographic exposures give an idea of the relative intensities of the radiant energy of different wavelengths or frequencies.

definite and unchanging parts. Thus the atomistic principle was finally applied to electromagnetic energy. Although this is discussed in a later chapter, the reader at this point may be interested in the picture which Planck drew. He used the electric charge (electron) in the atom as the source of radiation and concludes that it, which he calls an *electric oscillator* or *radiator,* emits light, discontinuously; that is, in elemental quantities which he terms *quanta.* Each radiator can emit only whole quanta. Thus, the reader will see that this is an extension of Lorentz's theory. One after another theoretical physicists dig deeper and deeper. Will they ever unearth the ultimate beginning of things?

Emission of Light

Doubtless, the reader has noticed what an important factor light is throughout these chapters and particularly in relation to the atoms. It was long ago shown that an atom of an element emitted light characteristic to it when the atom was free to exhibit its characteristic radiation. When light is passed through a prism a spectrum is produced, that is, light-waves of shorter wavelengths than others are bent further from the original path. In this manner the various components of the radiation emitted by atoms of matter can be studied and recorded. Gases give the characteristic *line spectra* of the elements whose atoms are involved in the molecules of the gas. However, these characteristic spectra are obtained only from the elements in a gaseous state. (See Fig. 10.) This suggests that in solids and liquids, which always give a continuous spectrum representing radiation of a great range of wavelengths, there is a dampening effect due, doubtless, to the more compact condition. The explanation involves atomic structure which is discussed in a later chapter. These characteristic spectra form the basis of that far-reaching branch

of physics known as *spectrum analysis*. This tool is far-reaching indeed, for elements in distant stars can be recognized by their spectra which are photographed here on Earth. As a consequence the elements of which celestial bodies consist are recognized. Incidentally, spectrum analysis can detect ultramicroscopic amounts of an element. It may be said to detect a billionth part of the minimum amount of an element necessary for detection by ordinary chemical methods.

It is natural that light should be intimately bound up in theories of matter, because elements reveal themselves by the spectral character (the wavelengths or frequencies) of light which they emit. (By light we mean any electromagnetic radiation, visible and invisible.) Light is the language of the atoms of elements. Each family of atoms speaks in its own dialect. There are resemblances which suggest certain relationships. The scientist cannot see the molecules and the atoms so he must be guided in his conclusions pertaining to them, by studies of the nature of the light emitted.

In the spectroscope, light of a certain wavelength exhibits itself as a line, which is an image of the slit of the instrument, displaced a certain amount from a straight path which depends upon the wavelength. Zeeman, in 1896, found that a powerful magnetic field in the space which was occupied by the atoms emitting the light, caused each spectral line to be split into more than one line. In the simplest case, the line is split into two lines, one on each side of the position of the original line. This revealed an influence of the magnetic field on the source of radiation — the electrons. Lorentz's electron theory explained this very saisfactorily. This is one of the many tests that it has passed. (See Fig. 11.)

The electron is assumed to be in periodic motion and light is a periodic disturbance. When two periodic processes of similar nature are superposed we should have the phenomena

of resonance. We strike the keys of a piano one after another. Finally, we strike one which makes a vase on top of the piano vibrate; then we find one which "rattles" the window-pane; and so on. When an object has a certain free period it will

FIG. 11. The Zeeman effect. The two spectral lines *a* appear as single lines of apparently simple structure. When the atoms, which are radiating energy of the frequencies represented by these lines, are subjected to a powerful magnetic field, the lines are resolved into complex groups, *b*. Based on the electron theory of atomic structure, the magnetic field retards some electrons and accelerates others in the atom which causes them to emit radiant energy of lower and of higher frequencies. A theory of atomic structure can not be successful unless it explains this phenomenon among others.

respond to a similar disturbance of the same period. A parade in step across a bridge endangers the bridge if the period of the steps is near the free period of the bridge. So it is with electromagnetic disturbances, and the production of the phenomena of resonance encouraged the belief that the electron in periodic motion was the ultimate source of light.

The frequencies of light-waves are very great. A frequency of 3×10^{15} (waves or cycles per second) is found for extreme ultraviolet radiation; 7.7×10^{14} for violet light; and 4×10^{14} for deep red light. In other words, if a wave of light is emitted each time an electron completes one revolution we must conclude that violet light is produced by electrons revolving nearly one million billion times per second. A molecule in a gas suffers several billion collisions per second. Therefore, only a fraction of a billionth of a second elapses between collisions. Still in this very small part of a second while a molecule is travelling its average short distance be-

tween collisions, something in the molecule is revolving about 60,000 times if it emits red light, and 120,000 times if it is emitting violet light.

The mechanism inside the atom is discussed further in a later chapter.

Other Evidence of Electrons

Many opportunities have presented themselves for studying the electron and for applying the electron theory to the explanation of experimental data. Until the electron was detected and studied, the hydrogen atom was considered to be the smallest mass in existence. However, the mass of the electron is now known to be about 1800 times smaller. In other words, 1800 electrons equal the mass of a hydrogen atom at the same velocity. The reader will note that in dealing with these particles which can move with high velocity, we must acquire the habit of specifying or of including the word *velocity* when making statements of mass.

If we connect the terminals of a tube, containing a gas at low pressure, to an electric voltage sufficiently great, the gas will become "excited" and the atoms will emit radiation. Usually, some of the radiation will be of frequencies to which the eye responds and we will see a luminous gas. So-called cathode rays pass in the direction from the negative terminal to the positive one. (See Fig. 12.) These are now known to be negative charges of electricity or electrons. It was found that they are deflected by an electric field like that between two plates which are connected respectively to positive and to negative terminals of a battery. It was also found that they are deflected by a magnetic field. Many measurements have been applied to these cathode rays. Inasmuch as these electrons could be made to move at different velocities up to that of light, they were interesting subjects. Much

was learned in regard to their properties. Here, for the first time, it was found that mass varied with the velocity. The term *cathode rays* was applied before it was known that they were electrons. Incidentally, cathode rays could travel from the Sun to the Earth in less than a half hour. It is possible that something of this nature is actually emitted by the sun, thereby causing the aurora borealis and possibly causing magnetic disturbances which are noted on Earth.

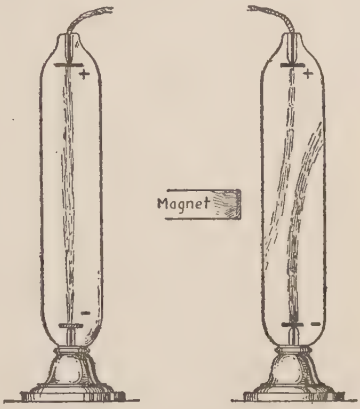


FIG. 12. Illustrating the electric discharge tube containing gas at low pressure. Cathode rays are electrons travelling from the negative to the positive electrode. Positive rays are positively charged ions of gas travelling from the positive to the negative electrode. These moving electric charges possess the characteristics of electric currents so that they are deflected by a magnet as shown.

Proceeding from the positive terminal of the low-pressure tube mentioned in the foregoing paragraph, are *positive rays*. These are larger bodies carrying a positive charge. Their magnitude is about that of ions in the process of electrolysis. On account of their large mass they move relatively slowly, at about one hundredth the velocity of light. They are deflected by electric and magnetic fields. Their mass is about equal to the atom of the gas, so it is possible that they are atoms which have lost an electron and are thereby positively charged.

The movements of these positively and negatively charged bodies in magnetic fields add proof that the moving charged particle has the same properties as an electric current. The electrons moving in circular orbits would produce a magnetic

field like a current flowing in a circular wire. Thus the electron theory opens up the possibility of accounting for *magnetism* by revolving electrons. Therefore, if all matter contained revolving electrons, magnetism could be considered a property of all matter. We thus have an *electron theory of magnetism.* Substances differ considerably in their behavior in magnetic fields. These differences are accounted for by the electron theory, by the direction of revolution of the electrons in the molecules or atoms. They may revolve in different directions so that their magnetic fields more or less neutralize each other.

It has been seen that a revolving electron represents simultaneously a small "fly-wheel" and also a small magnet. It occurred to Einstein that if the magnetic field could be reversed suddenly, the combined fly-wheel effect of all the innumerable electrons should by their inertia tend to turn a soft iron rod for a moment. This experiment was performed by de Haas with the result predicted.

Radioactive substances, such as uranium and radium, emit several kinds of radiation. The *gamma rays* are now known to be electromagnetic rays of very high frequency. The *alpha rays* are positively charged particles which are now thought to be *helium atoms.* The *beta rays* are none other than our familiar (negative) electrons. These electrons are emitted at velocities varying up to nearly the velocity of light. A great deal of information pertaining to electrons and also to the structure of atoms has been obtained by the study of the radiation from radioactive substances. These aspects of the foundations of the physical world are so important that chapters are devoted to them.

Chapter X

THE EVOLUTION OF ELEMENTS

Everyone is familiar with the futile but persistent efforts of the alchemists of old to transmute base metals into gold. Little did they suspect that in Nature a process of transmutation of elements had been going on for eons. If they had devoted themselves to methodical research instead of relying upon philosophy and mysticism, they may not have learned how to convert copper into gold, but they would have achieved some progress toward their desire. Furthermore, civilization would have enjoyed the fruits of experiments thousands of years before it did. The reader has seen that civilization progressed in many ways for thousands of years before they learned that the facts of experiment were the foundation stones upon which to construct theory.

In this chapter, the marvels of radioactive substances such as uranium, thorium, radium and their products are discussed. Studies of them have revealed many of the hidden secrets of matter. The uncommon properties of these elements and of their products and compounds are extremely interesting. There are so many attractive avenues that one is tempted to stray into them instead of following the purpose of this book which is committed to discussions of the foundations of the universe. Among the mass of data which could provide many chapters, the actual examples of transmutation of elements is easily lost sight of. However, from the viewpoint of the foundations of our physical world the most vital data yielded by radioactive substances are those cases of the birth

of one element from another. These marvelous transmutations are for the first time revealed to mankind by studying uranium, thorium and radium.

Here for the first time one sees the birth of an element from another. In truth one does not quite see the birth, but the newly arrived *alpha-particle which is a helium atom* expelled from one of the much heavier atoms of these radioactive elements, announces itself with a splash of light as it strikes a phosphorescent screen. Here for the first time man witnesses the effect of a single atom. There are other births too. Whole series of elements are born. Among these are a number of familiar ones. We may witness the transmutation of uranium eventually into actinium. We may also record the transmutation of uranium into radium. During these series of transmutations many helium atoms are born. It is a marvelous aspect of Nature which has been proceeding from a period so remote that it is lost in the speculations of our imagination. We are encouraged to believe that the key which unlocks the atom for us may be found in these examples of evolution of atoms. With this key what power the human race will have! Such power would dwarf into insignificance all the combined power that monarchs have possessed throughout the ages. It could be a power for good or for evil. It would be better hidden until Man could be depended upon to use it for the benefit of Man.

Discovery of Radioactivity of Elements

In 1895 Röntgen announced his discovery of radiation of marvelous properties. These Röntgen rays were so mysterious for a time that they were termed *X-rays*. Objects which were opaque to any known radiation were quite transparent to Röntgen rays. Now we are quite familiar with the pene-

trating properties through their many practical applications. Fortunately, the transparency of various objects usually varies sufficiently so that shadows of various densities are produced and these are recorded by a photographic plate or a fluorescent screen. These rays are now known to be electromagnetic waves of extremely high frequency and short wavelength.

Röntgen's discovery immediately suggested the possibility that similar radiation might be emitted by sources of light along with the usual radiation. Becquerel made the happy choice of a uranium salt for such an experiment. It was known for years that some uranium salts exhibited the property of phosphorescence; that is, after exposure to light (and some invisible radiations) it will continue to emit light for some time. This should not be confused with the glow of phosphorus which is a chemical process. True phosphorescence and fluorescence (of extremely short duration) are molecular phenomena due to some kind of displacement of electrons temporarily.

After a fortunate selection of a uranium salt by Becquerel a fortunate accident occurred. The uranium salt was placed on a black paper in which a photographic plate was wrapped. The salt was experimented with by "exciting" the phosphorescence by exposing it to sunlight. Becquerel had already found that the photographic plate was blackened by radiation penetrating the black paper, but he naturally attributed this to the phosphorescent radiation. One day when he was about to try the experiment again the sun was obscured, so he placed the wrapped plate with the uranium salt upon it in a drawer and forgot it for several weeks. When his attention turned to the subject again he had the inspiration to develop the plate to see if anything had happened without the salt being excited to phosphorescence by exposure to light. He found the plate blackened. Thus he discovered a new prop-

erty of uranium, for he easily proved that the uranium emitted radiation itself without the aid of any excitant. He then proceeded to make shadow pictures of various objects by the radiation from the uranium just as Röntgen had done with X-rays. Thus radioactivity of elements was discovered.

Now it is easy to obtain small amounts of radium salts so that anyone may make these shadow-pictures. Thorium is an ingredient of gas-mantles, although only a small amount of it is present. Nevertheless, a shadow picture of the mesh of a gas-mantle has been made by leaving it for a few weeks in contact with the black paper in which a photographic plate is wrapped. (See Frontispiece.)

An Inherent Property of the Atom

Although uranium and all its compounds are radioactive, the practical applications and even the scientific experiments would have been limited had not Mme. Curie and her husband discovered radium. This is millions of times more radioactive than uranium. It naturally occurred to Mme. Curie and others that there might be other elements which possessed this inherent property of radioactivity. However, after a careful investigation of the elements known at that time, thorium was the only one that exhibited this property.

It was soon learned that uranium was active in all compounds regardless of its source, and that this property could not be altered or destroyed. It goes on emitting radiation in its own natural way regardless of any treatment which mere Man has applied. This indifference is also exhibited by all other radioactive substances. Therefore, radioactivity may be considered an inherent property of the atom. Obviously, until Man has found a way of altering this property he is far from the ultimate goal. Here we have the process of trans-

mutation going on. Here we have atoms giving up some of their great store of energy. One who knew the complete secret probably could cause the greatest upheaval imaginable in our economic life. If gold could be manufactured at low cost and if practically unlimited supplies of atomic energy could be easily obtained, we can imagine what might happen. However, we do not yet know how the atom is put together or how to pull it apart, although our knowledge is growing rapidly.

As stated in a previous chapter, the radiations emitted by radioactive elements are of three kinds, *alpha* (α) *particles, beta* (β) *particles,* and *gamma* (γ) *rays.* The alpha particles are positively charged and are now known to be *atoms of helium.* They are discharged from their parent atom with a velocity less than one-tenth that of light. The beta particles are negative charges of electricity and are now known to be electrons. Some of these are emitted at velocities nearly as great as that of light. (See Fig. 13.) Gamma rays are electromagnetic waves of very short wavelength and high frequency. They are of higher frequency than Röntgen rays although the frequency of the latter is more or less under our control. An atom of a radioactive element on emitting one of these particles, for example, becomes an atom of an element of lower atomic weight. This atom now may emit a particle thereby becoming an atom of a different element of still lower atomic weight. This process goes on until a uranium atom through a series of steps has evolved into a radium atom. The latter then continues through a series of transmutations until apparently it becomes lead.

All the atoms of uranium do not emit these particles or undergo the same transmutations simultaneously. As far as we know, each atom (with certain exceptions) goes through the same series of steps, but not in parallel with any other atoms necessarily. Owing to the great number of atoms the

law of averages reigns as in the case of the collisions of molecules in gases. Just as the pressure on the walls of a vessel containing a gas is apparently the same over all the area, the progress of radioactivity of a substance seems to be as uniform as though it were a property of the body as a whole and not of myriads of atoms each starting on its evolutionary course quite independently of the others.

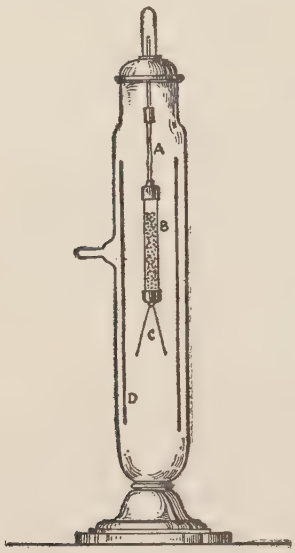


FIG. 13. The uniformity of the rate of disintegration of radium is illustrated by this "radium clock" devised by Prof. R. J. Strutt (now Lord Rayleigh). A radium compound in a thin glass tube *B* is supported by a quartz rod *A* which is not a conductor of electricity. The beta-particles (electrons) are expelled through the thin walls of *B* leaving the radium compound and gold leaves *C* positively charged. The leaves *C* gradually separate by repulsion as the positive charge accumulates until they are finally discharged when they touch the metal tube *D*. They collapse and the same cycle is repeated. The period of the cycle is practically constant for years, because the activity of the radium decreases to half-value in 2500 years.

The radioactive strength of an element diminishes continually in proportion to the number of atoms that are undergoing evolution. Thus the strength is said to decay. For some reason some atoms may start to disintegrate now and some may not for an extremely long period of time; therefore, the decay of radioactivity extends over an infinite period of time theoretically. Therefore, it is customary to measure the *average life* or *half-period*. The average life of various atoms in any radioactive series differs greatly — from a fraction of a second to millions of years — as seen in later paragraphs.

The radioactivity of radium is such that its average life is 2500 years. A billionth part of an ounce is easily detectable by means of a gold-leaf electroscope. The charged particles emitted by radium and its products can be utilized in charging or in discharging an electroscope (Fig. 13), thereby exhibiting the presence of radioactive atoms. If an ounce of radium were divided equally among all the human beings on Earth, each would have a sufficient amount of radium to be readily detected by very simple means.

The Work of the Curies

The names of Mme. Curie and of her husband are emblazoned in the Hall of Fame because of their discovery of radium, which is the most powerful source of radioactivity known at present. After a thorough study of this property of uranium, it was concluded that the minerals containing this element were more radioactive than could be accounted for by the actual amount of uranium present. Pitchblende often contains a large percentage of uranium oxide. Some specimens were several times more radioactive than pure uranium oxide. Naturally this led to the query: Is there some other radioactive element present? The Curies answered this question in the affirmative by the discovery of radium. Their work is one requiring extreme patience and painstaking, for in a hundred tons of pitchblende only a fraction of an ounce of pure radium is likely to be found. The pure radium is a million times more radioactive than an equal quantity of the original pitchblende and is several million times more active than pure uranium.

An army of scientists has been studying radioactivity since it was first discovered and a wonderful picture has been revealed. All the hidden transmutations are perhaps known at the present time. Possibly other radioactive elements still

remain unknown, but this is not likely. In experimental physics we have cases where an electron is shaken out of an atom. This is a step toward reproduction of Nature's radioactive process.

Evolution of Elements

The changes which take place are such that an atom of lower atomic weight is the residue of an atom of higher atomic weight after it has emitted or lost something by radiation. Thus the uranium atom has an atomic weight of about 238 relative to oxygen at 16. It expels an alpha particle and the remainder of the atom has an atomic weight of 234, which is a new element termed uranium X_1. It is the chemical equivalent of thorium. This process goes on for four more transmutations until the element *radium* is produced with an atomic weight of 226. In other words, a uranium atom which loses a total of three alpha particles (helium atoms) and two beta particles (electrons) during its five transmutations into as many different elements, becomes a radium atom. But the process does not stop here, for the radium atom undergoes nine transmutations, during which series five alpha particles and four beta particles are lost. The end-product is an atom with an atomic weight of 206 which is the chemical equivalent of lead. (See table.)

If the uranium atom and all the succeeding ones between it and the final end product (lead?) happened to be of average life in each case, the process outlined in the foregoing paragraph would span a period of time greater than eight billion years. The periods of time that this "average" atom would exist in each of its states varies considerably. It will have existed as 14 different atoms. It would remain a uranium atom for eight billion years; an ionium atom for 100,000 years; a radium for 2500 years; as radium emanation (a

gas) for about $5\frac{1}{2}$ days; as radium C^1 for only one millionth of a second.

Now if we consider an appreciable amount of uranium we would have an enormous number of atoms present. The results on the average would be those described in the preceding paragraph. Thus it is seen that any mineral in its natural state containing uranium contains also all the products of the series in the proportions determined by the average life of the different products. All these data have been sifted out through persistent experimentation.

A series of transmutations of radioactive elements can be best shown in the form of a table because certain pertinent data such as atomic weight and average life can be included. Therefore, the three chief series are presented herewith. The *main series* is that from uranium through radium. However, at uranium I or uranium II a branch of the main series forms. Here, 8 per cent of all the atoms evolve in a different series which passes through actinium. This is termed the *actinium series*. The *thorium series* is also presented. It will be noted that the end-product of each series is a chemical equivalent of lead (or nearly so) although the atomic weights differ. Inasmuch as there is some difference in the data presented by various authorities, it seems best to limit the data presented in the tables herewith to a single authority. Therefore they are practically the same as presented by Frederick Soddy, who has contributed much to this branch of physics. It will be noted that each atom after emitting an alpha particle shows a decrease in atomic weight equivalent to the atomic weight (4) of a helium atom. The emission of an electron does not appreciably alter the atomic weight. In the accompanying tables the parent of any atom is the one just above it in the series. By *chemical equivalent* is meant an element exhibiting the same properties.

THE DISINTEGRATION OF URANIUM

The Main Series

Element	*Atomic Weight*	*Particle Emitted*	*Average Life*	*Chemical Equivalent*
Uranium I	238	alpha	8 billion years	uranium
Uranium X_1	234	beta	35.5 days	thorium
Uranium X_2	234	beta	1.65 minutes	ekatantalum
Uranium II	234	alpha	3 million years (?)	uranium
Ionium	230	alpha	100,000 years	thorium
Radium	226	alpha	2440 years	radium
Rad. Emanation	222	alpha	5.55 days	emanation
Radium A	218	alpha	4.3 minutes	polonium
Radium B	214	beta	38.5 minutes	lead
Radium C	214	beta	28.1 minutes	bismuth
Radium C^1	214	alpha	one millionth second (?)	polonium
Radium D	210	beta	24 years	lead
Radium E	210	beta	7.2 years	bismuth
Radium F	210	alpha	196 days	polonium
End product	206	....	infinite (?)	lead
		(At Radium C, 3 atoms of each 10,000 atoms branch off as follows)		
Radium C	214	alpha	28.1 minutes	bismuth
Radium C_2	210	beta	1.9 minutes	thallium
End product	210	....	infinite (?)	lead

At uranium I or uranium II, a branch of the main series of uranium is formed by 8 atoms of each 100 atoms branching off to form the actinium series. The series consists of ten different products or atoms, the end-product being lead having the atomic weight of 206 or 210.

Another interesting series is that of thorium which is given herewith.

THE DISINTEGRATION OF THORIUM

Element	*Atomic Weight*	*Particle Emitted*	*Average Life*	*Chemical Equivalent*
Thorium	232	alpha	25 billion years	thorium
Mesothorium I	228	beta	9.67 years	radium
Mesothorium II	228	beta	8.9 hours	actinium
Radiothorium	228	alpha	2.75 years	thorium
Thorium X	224	alpha	5.25 days	radium
Th. Emanation	220	alpha	78 seconds	emanation
Thorium A	216	alpha	0.2 second	polonium
Thorium B	212	beta	15.4 hours	lead
Thorium C	212	beta	87 minutes	bismuth
Thorium C^1	212	....	very short	polonium
End product	208	....	infinity (?)	lead

(At Thorium C, 35 atoms of each 100 atoms branch off and form a series as follows)

Thorium C	212	alpha	87 minutes	lead
Thorium D	208	beta	4.5 minutes	thallium
End product	208	....	infinity (?)	lead

Atomic Energy

It seems to be proved beyond question that radioactivity is a property of the atom and that one atom by the emission of radiation becomes a new element. For example, when a radium atom expels a helium atom it becomes an atom of (radium) emanation. The radium atom and the emanation atom are distinctly different; furthermore, they are just as definitely atoms as any of those of any other element. One might ask why radium is not considered a chemical compound each of whose molecules consist of one atom of helium and one of emanation. However, if this were the case the characteristic spectrum of the compound would exhibit the helium lines, that is, the helium spectrum. Here is where the spectroscope is unfailing. It will reveal atoms regardless of their chemical combination with others. But the spectroscope does not reveal the presence of helium in the spectrum of radium. In fact, the spectrum of radium is just as distinctly characteristic as the spectrum of any other element. The helium atom is tucked away in the atom of radium in some manner so that it becomes an elemental part of the atom. It loses its identity; it is completely woven into the radium atom. Why and how it is expelled is still a mystery. This same discussion applies to any other radioactive atom.

Until radioactivity was discovered, scientists may have dreamed lightly of stores of energy within the atom, but they did not *know* that enormous stores of energy were there. They knew of the potential energy bound up in chemical compounds, but of atomic energy nothing was known. Even now

there is some question whether the energy of the emitted particles before emission is stored outside the atom or within it. The most probable theory is that they are within the atom. This point is of little importance here as compared with the fact that the stored energy is enormous. The total energy that we have experienced in tides, waterfalls, winds, moving bodies, chemical compounds, etc., is insignificant compared with the total atomic energy.

A gram of pure radium has been found to produce 133 calories of heat per hour; that is, enough heat to raise the temperature of 133 grams of water one degree Centigrade. Its average life is about 2500 years, therefore, during its life-time this gram of radium would emit about three billion calorries. The total energy evolved by this gram of radium is about a million times that of an equal weight of coal and oxygen. Expressed another way a pound of radium evolves as much energy in its life-time as 400,000 pounds of high-grade coal evolve when burned. However, this energy from radium is gradually evolved over a period of 2500 years. Uranium evolves slightly more energy than the same amount of radium. A pound of uranium oxide costing at present only a few dollars evolves more energy than 150 tons of coal. In other words, a cupful of uranium oxide will generate as much heat in its life-time as several carloads of coal. But if we are unable to hasten the disintegration (and we cannot until we find the key which unlocks the atom) we must wait as patiently as possible for eight billion years to elapse before we will have obtained this total energy from the uranium. Thus the secret of transmutation of elements will not only make gold for us from copper, but will also release the atomic energy which is worth more than the gold.

Little attention has been given to the *gamma rays* emitted by radioactive elements, because they are not of primary in-

terest from the viewpoint of this chapter. The emission of them by atoms is just as marvelous as the emission of helium atoms and electrons. They are electromagnetic waves usually thousands of times shorter in wavelength or higher in frequency than visible radiation. Their extremely short wavelength indicates that they are produced by electrons revolving in orbits of very small diameter. In fact, they may be due to electrons revolving in the *nucleus* of the atom rather than around the nucleus.

Radioactivity and the Universe

There are many interesting aspects of radioactivity which are beyond the scope of this book. Indeed, we do not have space for many of those which have a bearing upon the foundations of the physical universe. We must be content with only a few glimpses. Man has long pondered over the great forces and vast processes which have been at work in the celestial bodies of the universe. In the evolution of the universe time is plentiful. The processes can go on ever so slowly and still accomplish their ends. The few thousands of years of Man's recorded history are insignificant ticks of the cosmical clock. Billions of years are but a moment when infinite time is available. Into this great world-evolution we must now introduce the possibilities of radioactivity. The powers of the small amounts of radioactive elements which Man has isolated seem relatively feeble, but by multiplying these by the countless tons of them in the universe and by almost infinite time, we see that wonders could have been achieved by atomic energy.

The celestial bodies have been losing energy by radiation for countless ages. Some ingenious explanations of the sources of the energy have been put forward. To these must be added

the energy of disintegrating atoms. Whether or not atomic energy dissipated by such atoms has played a major part on the cosmic stage need not concern us as long as we do not know. However, these processes are slow enough and powerful enough to supply the continuous radiation of energy from the celestial bodies. They can account for the fact that all these bodies are not lifeless and covered with ice. Strutt has shown that only a reasonable amount of radioactive elements in a crust of the Earth fifty miles in thickness is sufficient to account for the entire amount of heat that is being lost into space by the Earth. While this conclusion appears safe for a relatively cool body like the Earth, it does not appear applicable to an incandescent body like the Sun. An incandescent body loses energy at a much greater rate than a cool body. The loss of heat is proportional to the fourth power of the temperature. There is no indication that the Sun or the other incandescent stars contain radioactive elements in sufficient quantities to account for a rate of loss of heat millions of times greater than that of the Earth. Nevertheless, this does not mean that atomic energy of some kind and in some way is not a vital factor in supplying the heat of the stars.

It may be natural to wonder why, after all these countless eons during which the Earth has existed, there is any radium left if it is continually disintegrating. Its average life is only 2500 years, but some of the atoms do not disintegrate for many thousands of years. At the end of 25,000 years only one out of each original thousand atoms remains of a quantity of radium. On this basis there would be no appreciable amount of radium left now. Let us now look forward. Considering only the amount of radium in the Earth now and its rate of disintegration, there would have had to have been a million million times as much radium in existence only 100,000 years

ago as there is in existence now. In other words, the Earth would have had to consist of solid radium. Both conclusions are incorrect because they have not taken into account the source of radium. Its parent is uranium, the average life of which is eight billion years. The conservatism of this parent saves the day for us.

Owing to the extremely slow disintegration of uranium, the total quantity of uranium is practically constant over long periods of time. This means that radium is being produced practically as fast as it is disintegrating. If we go back eight billion years we find only twice as much uranium as exists today. Thus it is seen that the question of the existence of radium now is easily explained.

Doubtless readers unfamiliar with the subject will wonder how these long periods are measured. We know how far it is from the Earth to the Sun and we found out without stepping off the distance. So it is with uranium. Indirect methods are often used in science and sometimes direct methods are easily devised. Careful determinations have shown that 3,200,000 parts of uranium are always present in minerals for one part of radium. Knowing that the life of radium is 2500 years, it follows that that of uranium is 8,000,000,000 years. How about the life of radium? It was determined just as easily as that of uranium.

Chapter XI

INSIDE THE ATOM

Four centuries have elapsed since Copernicus defied bigotry and announced his belief that the Earth and the other planets of our solar system revolved in circular orbits around the Sun. A century later Kepler completed the work by developing his famous laws of elliptical orbits for these celestial bodies, which are now known to be true. Little did they dream, as they dealt with the enormous distances and masses of the bodies of the solar system, that they would have their counterparts centuries later developing the same ideas for "solar systems" of infinitesimal magnitudes. Nevertheless, this is the recent trend of science in trying to picture the structure of the invisible atom. Likewise, Newton when he developed the laws of motion for bodies was looking with ever-expanding imagination for applications of his ideas to the explanation of the movements of celestial bodies. Little did he dream that his laws modified by new knowledge would eventually be applied to infinitesimal masses in the atoms which he did not know existed.

We have witnessed the success of the kinetic theory of matter. We have seen phenomena, such as light-waves, explained on the basis of mechanical theory, suddenly revealed as electrical phenomena. We have had glimpses of atoms and of particles emitted by them. We have seen matter and mechanics gradually become associated with electricity. We will not be surprised to find the most advanced ideas contemplating all matter as electricity in motion. Many interesting

experimental facts have not been touched upon. Some of these will be discussed in due time, but it appears best to pause at this point for a peep into the atom. We have reached a difficult stage in the logical presentation of the foundation of the physical world. Up to this time science developed slowly enough and along few enough paths to enable us to follow its course systematically along the different paths. Now they are converged, multiplied and over-run each other. With the discovery of the electron, radioactivity, the quantum of energy, and other foundational or near-foundational things and processes, scientific development has been very rapid. The picture of recent activities is a complex one, but it is encouraging to know that the picture of Nature still promises to be simple.

Inorganic Evolution

Evolution has become recognized as a basic factor in organic life. The great work of Darwin and others has shown that this slow, but irresistible process, is going on continually in the world of plants and of animals. But it is not limited to the world of living things, for we see evolution at work in the inorganic world. As we look upward at the brilliant gems in the night sky we may wonder what evolutionary processes are going on. We know our Earth was not always just as it is. We know it is changing even now. We look through the powerful telescope which reveals millions of stars to us and we see celestial bodies in every stage of evolution. Nearly a million spiral nebulae are seen in their process of twisting themselves into celestial spheres. Stars that have passed this stage are revealed in all phases of evolution, from the glowing blue-white-hot stage to cold planets. In radioactivity we have witnessed the evolution of elements from

higher atomic weight to lower ones. Here in lifeless matter, evolution is going on slowly with the precision of clockwork, guided only by a hidden hand of Nature. In examining the spectra of electromagnetic waves emitted by the stars, it appears that the hotter the stars the fewer are the elements it contains. In the hottest stars it appears that only the simpler elements are present, such as hydrogen and helium, although some of the elements of higher atomic weights seem to be partially formed. In the cooler stars, elements of higher atomic weights are found. If this is true, we are confronted with evidence of the evolution of elements.

Thomson's Atomic Structure

Theories based upon sound mathematical philosophy and upon as many facts as possible are the charts which guide the imagination over unexplored regions. Such theories in modern times are usually sound enough to be of great service even though they must eventually be radically altered. They suggest many experiments which would not likely be conjured up in the mind's eye otherwise. Such a service was rendered by J. J. Thomson when in 1904 he drew mathematical pictures of various atoms. These were the most plausible up to that time, particularly in the new light which the discovery of the electron had shed upon the mystery of matter. He started with the facts that unit electric charges exist as what we term *electrons* and that no smaller positive charge than the hydrogen ion had been isolated. He pictured the atom as consisting of a comparatively large sphere of positive electricity, uniformly distributed, and inside this sphere electrons were arranged in certain geometrical configurations in such a manner that the entire atom was stable under the electric forces. Here we have an atom consisting solely of electricity.

In order to make the mathematical treatment reasonably simple he arranged the electrons symmetrically around the circumferences of circles whose centers coincided with the center of the sphere of positive electricity. The electrons would repel each other (all being negative) and the ring of electrons would tend to enlarge. The positive electricity by its attraction for the negative charges would tend to prevent this, so the configuration remained in equilibrium under these two opposed forces. The ring of electrons was assumed to rotate in its own plane with the center of the "positive sphere" as an axis. It is obvious that the force of attraction of the positive electricity must be greater than that necessary to hold the electrons when stationary, because when in circular motion a force toward the center is necessary to maintain the movement in the circle. This additional force is like that of the Earth necessary to change the direction of the Moon's motion continually in order to keep it moving in a closed orbit.

As already stated, Thomson distributed the electrons in rings in the same plane in order to avoid three-dimensional space in his mathematics. He built up stable arrangements of electrons which represented hypothetical elements. The simplest type would be a single electron at the center of the positive sphere. The next type would be the simplest stable arrangement of electrons in one ring. He determined the possible stable systems. As the number of electrons increased, stability required that they be placed in two or more concentric rings. Of course, the amount of positive electricty was increased as the number of electrons increased. Each new ring may be imagined to represent a "period" in the periodic table of elements. The first element in each period might result from the addition of a new ring with only one electron. As the number of electrons increased in the new ring the ele-

ment shifted along from space to space in the corresponding period of the table.

It should be obvious that the stability of each of the possible arrangements is not the same; in other words, some of these hypothetical atoms can readily lose an electron or by gaining an electron they can become more stable. As the number of " rings " of electrons is increased it is obvious that a number of atoms can have the same number of electrons in the outer ring, for example, because the change in arrangement can take place in the other rings. This suggests the possibility of explaining the similarities indicated by groups and periods in the periodic table. If the arrangement of electrons is such that it is relatively unstable, it is easy for this atom to add an electron. Electro-positive and electro-negative elements are explained. Valency is predicted. In various ways Thomson's theory of atomic structure was astonishingly satisfactory in explaining facts of elements. However, recent knowledge seems to demand modifications. Even though Thomson's model is abandoned it will always be credited with having served marvelously well in the development of the theories of atomic structure.

The Nucleus

In the development of theories of atomic structure which involve only electricity, it seemed necessary to have approximately as much positive as negative electricity. The electron had become well known as the ultimate unit of negative electricity. It had been utilized in many ways in the explanation of electrical phenomena so that when science was ready to construct atoms, it offered less difficulties than positive electricity. It has been seen that Thomson incorporated various numbers of them in his hypothetical atoms in more or less stable arrangement which explained various facts of elements

and of their chemical combination. However, Thomson gave little attention to the positive electricity in the atom. Certainly some means of subdividing the positive electricity had to be conceived so that it too could be varied to suit the requirements.

The alpha particle emitted by some radioactive elements was finally recognized as a helium atom with a positive charge of electricity equal and opposite to two electrons. It was naturally suspected that the alpha particle or helium atom was an elemental part of the atom. It is about four times the mass of a hydrogen atom and its charge is twice the magnitude of the electron, so it could not be the fundamental " brick " of positive electricity. Might not the hydrogen atom after losing an electron (becoming a hydrogen ion) be the unit of positive electricity — the proton? It will be recalled that a century ago Prout made a bold hypothesis in which all elements were built up of hydrogen. He had little experimental data to support his suggestion. In fact, the fractional atomic weights were prominent data which could not be reconciled with it. It is quite likely that he had little to support him, but a " reasonableness " born of faith in a simple natural scheme. However, a hundred years later the *hydrogen ion* is found playing a stellar rôle in the theory of atomic structure.

Rutherford attacked the atom not only figuratively, but actually. What better method could be devised for learning something of the parts of the atom than by bombarding the atom with small missiles. From his experiments he concludes that the positive nucleus of the atom is relatively small compared with the total diameter of the atom. This was determined by the deflections of the alpha-particle projectiles due to the atom. He placed a radioactive substance near a thin sheet of an element, for example, gold foil. Alpha particles emitted by the radioactive material passed through the foil.

He knew their angle of incidence and could determine the direction of emergence of each particle. In this way he could determine the scattering due to the atoms of gold and of other elements. He came to the conclusion that the positive nucleus of an atom of gold was only a ten-thousandth of the diameter of the atom and that the positive electricity was concentrated in a volume about one millionth of a billionth of an inch in diameter or 10^{-12} inch.

From the study of the scattering of alpha particles in passing through hydrogen gas it was concluded that alpha particles passed so very close to the center of the atom that the positive nucleus is smaller than an electron. Evidence indicates that the positive nucleus of a hydrogen atom possesses practically the same mass as the whole atom. This means that the electron contributes practically nothing to the mass of this atom. Assuming that the mass of the hydrogen atom is entirely electrical, the nucleus of this atom is about 10^{-25} inch in diameter, about 1800 times the mass of an electron, and about one eighteen-hundredth the diameter of an electron.

Such data were not available when Thomson made his first attempt to build up hypothetical atoms by more or less stable arrangements of electrons in rings. In the light of later knowledge his model had to be revised, particularly that portion pertaining to the positive electricity. It seems that the small nucleus must replace his relatively large sphere of positive electricity.

The Proton

The existence of the electron as the ultimate "atom" of negative electricity was thoroughly established some time ago. These gave rise to the idea of the existence of its complement —a unit of positive electricity. However, the "atom" of positive electricity has been more elusive; nevertheless, this

complement, which is termed the *proton*, now seems to be a reality. For a long time about all that could be said with any degree of certainty was that the electrons in an atom must be associated with a positive charge whose magnitude was equal to the number of electrons multiplied by the known value of this elemental quantum of electricity. Our knowledge of the proton has come largely from experiments with radioactive elements and with the phenomena of conduction of electricity through gases.

It will be recalled that beta particles (electrons) are emitted by radioactive atoms at very high velocities approaching that of light. It is well known that water-vapor condenses around small particles such as dust. This can be demonstrated by suddenly expanding the atmosphere above the surface of water in a closed vessel. A visible cloud forms which gradually settles. If this process is repeated several times, permitting the cloud to settle to the water surface each time, the air is almost completely freed from the fine dust particles. It is then difficult to form a cloud because of the scarcity of nuclei upon which the vapor may condense. However, if the air is ionized by ultraviolet radiation, by collisions of swiftly moving particles, or otherwise, the electrons and ions of gas will perform the function of nuclei for the condensation of the water vapor. If a swiftly moving electron passes through the air laden with water-vapor, it will ionize some of the molecules of gas; that is, separate them into atoms or relieve them of an electron. Upon these ions water-vapor will condense and the droplets of water can be seen. Thus the path of an electron can be distinguished. However, experiment shows that a beta particle ionizes only about one in 10,000 of the molecules through which it passes. Perhaps it moves too rapidly in most cases to displace an electron from an atom.

An alpha particle moves with velocities from one to ten per cent that of light and its mass is thousands of times greater than that of an electron. It ionizes millions of molecules of gas during each inch of its journey. Its path is in a straight line until its kinetic energy is nearly spent by its many collisions. Then it is deflected more or less, but perhaps only by a head-on collision with the actual nucleus of an atom. This straightness of path and absence of deflection indicates that the nucleus of the atom (at least of gaseous atoms) is relatively small.

As already stated, Rutherford computed the probability of deflection of an alpha particle as it passed through thin sheets of metals. The relatively few deflections encouraged the belief that the nucleus of the atom is small.

A great deal of data has been obtained from studies of *positive rays* by the method devised by J. J. Thomson. When an electric discharge is produced through a tube containing gas at low pressure, a stream of positive ions passes from the positive to the negative terminal. *Cathode rays* also pass in the reverse direction. (See Fig. 12.) Both the positive rays and the cathode rays are deflected by magnetic and electric fields, the amount of deflection depending upon the velocity, charge, and mass of the particles. The velocities of the positive ions in an electric discharge-tube are usually much less than those of alpha particles from radium and other radioactive elements. From the strengths of the electric and magnetic fields and their deflections of the particles, various facts can be ascertained. It was found that these positive rays consisted of atoms of the gas which had lost usually one electron. Mercury atoms were found to have lost one, two, and three electrons.

One of the greatest triumphs of this method was the determination of the isotopes mentioned in Chapter VIII. For

example, in neon gas there were found to be two kinds of positive ions which differed only in mass. From the computations it was determined that neon atoms were of two different atomic weights respectively, 20 and 22. They are always present in neon gas in the proportion which results in an average atomic weight of 20.2. These two atoms of neon have identical chemical properties so they are termed *isotopes*.

Aston, who utilized the "positive-ray" method in the search for and study of isotopes, made a careful study of the hydrogen ion, which is known to be the *proton* or elementary positive charge of electricity. He corroborated chemical determinations of the mass of a hydrogen atom by also finding its mass to be 1.008. Therefore, it can be considered as definitely established that the proton or the nucleus of the hydrogen atom has an atomic weight of 1.008. The work of Aston in isolating the proton definitely established the elementary unit of positive electricity.

From other data, the proton or hydrogen ion is now considered to be the unit of which the (positive) nuclei of atoms are built and is responsible for the mass of the atom. For example, a helium atom consists of four hydrogen atoms. But can this be true when the atomic weight of helium is 4 and that of the free proton or hydrogen atom is 1.008? It would seem that the helium atom would have a mass equivalent to 4 times 1.008. It will be recalled that mass is now considered to be electromagnetic and dependent upon the velocity with which the body is moving. The mass is due to the electromagnetic field of the moving electric charges. Mass is no longer considered to be something in the body, but in the space around the body. When hydrogen atoms are grouped to form the nuclei of heavier elements it is easy to imagine that by their intimacy the electromagnetic forces are altered.

Two electric charges relatively distant from each other would have a combined electromagnetic mass equal to twice that of either one. When close together their combined mass is easily conceived to be less than the sum of their masses. This was pointed out as a possibility by Thomson when he created the idea of electromagnetic mass. From what is known of the nuclei of atoms, they may be considered to be very compact. The four atoms of hydrogen are so arranged in the helium atom that their combined mass is 4, or 8 parts in 1000 less than the sum of their individual masses.

Where does this mass go to when this grouping takes place? We cannot say it disappears without having it reappear as something else. The theory of relativity considers *mass and energy to be interchangeable.* It is sufficient to suggest at this point that the disappearance of 0.8 per cent of the mass of each hydrogen atom when it is employed as a "brick" for constructing nuclei of other atoms results in an equivalent quantity of *energy*. Where does the energy go? In the first place we did not pack these hydrogen atoms into other atoms. Man has not succeeded in doing this. The alpha particles were made in Nature's own way and time, both of which are secrets hidden from us as yet. The hydrogen atoms were packed into helium atoms and other atoms perhaps when this bit of the universe — the Earth — was a part of a white-hot star. There is evidence that such a process is going on in distant stellar crucibles even now. It may suit our imagination to account for some or even most of the heat of the stars by this "left-over" — this change of 0.8 per cent of all mass into energy, thereby accounting for the high temperature of those stellar bodies where the packing process — the formation of elements of higher atomic weights — is possibly taking place. Such a by-product would be enormous, for it would be an ever-increasing toll as the element became heavier,

assuming that all elements are built up of hydrogen ions and electrons. This is the favored theory of atomic structure at the present time. In regard to the suggestion of accounting for some of the energy (heat) of the stars in the foregoing manner, let us assure the reader that, while this seems plausible and possible, it is included here merely for the imagination.

Bombarding the Atom

Let us refer again to Rutherford's bombardment of atoms by means of alpha particles. Although ions had been produced by various means, Rutherford in 1918 was the first to disrupt the atom. After years of study of radioactivity it is natural that he tried to produce artificially what he saw Nature was doing continually. The emission of an alpha particle by an atom is a spontaneous disruption of its positive nucleus according to modern views of atomic structure. Why the atom should do this is a mystery and it was natural for this modern genius in experimental and theoretical physics to attempt to shatter the atom. If this could be done, a study of the parts should reveal something of the mechanism. He bombarded nitrogen molecules by means of alpha particles emitted by one of the radioactive elements of the radium series and found that the disruption of the nuclei of nitrogen atoms resulted in the production of hydrogen nuclei. He also disrupted the atoms of boron, fluorine, phosphorus, and aluminum with the same results. This immediately supplied support to the theory that elements were built up of ions of hydrogen and of electrons.

Alpha particles are emitted by different radioactive elements at different velocities. In other words, alpha particles from one source will penetrate a greater or smaller distance into the air, for example, than those from another source.

The scientist is thus situated like a hunter with rifles of various powers. The projectile, whether a minute alpha particle or a rifle bullet, travels through any medium until its kinetic energy is dissipated by collisions. It may also be deflected more or less, depending upon various factors.

Alpha particles can be detected by the splashes of light or scintillations which they produce when they strike a phosphorescent substance. This is how we are able to see for the first time the actual effect of a single particle of atomic size. This particle, in order to produce a splash of light, must still possess enough kinetic energy when it strikes the phosphorescent substance to agitate the atoms of the latter so that they emit light. By observing the presence, number, or absence of these scintillations it is seen we have a method which is useful in experimental physics. This method was used with great success by Rutherford, Marsden, and others.

When hydrogen gas was bombarded by alpha particles, scintillations were discovered on a phosphorescent surface of zinc sulphide at a distance three times further than alpha particles themselves penetrated. This meant that something else was causing the splashes of light. Rutherford proved that they were due to the nuclei of hydrogen atoms which possessed a positive electric charge equal to the proton. These were termed *H-rays*. When nitrogen gas was bombarded by alpha particles a similar result was obtained. Here again it was proved that the nitrogen atoms were shattered and hydrogen nuclei were recognized as being parts of the nitrogen atom. The experiments were continued with other atoms and H-rays were found to result from the shattering of atoms of a number of different elements. In some cases the H-rays did not appear to be liberated. Perhaps the atoms in these cases were not shattered completely enough. Much more work needs to be done along this line, but there is enough evidence

to encourage the belief that the atoms of elements have hydrogen nuclei — protons — associated with their nuclei in a fundamental or structural manner. Certainly we have many cases of disintegration of atoms, by the relatively great forces developed in their collisions with alpha particles moving at tremendous velocities, with a resultant liberation of something equivalent to the nucleus of the hydrogen atom. Considering that hydrogen, as a distinct element, was not originally present in these cases, the result is portentous. Atoms have been pried open slightly for our mind's eye. There is great promise that it will not be long before we have the parts of all of them on display.

Electrons and the Atom

Experimental physics has revealed many cases of emission of electrons and many practical applications of this phenomenon have been made. The radio-tube depends for its existence upon the emission of electrons by the filament. Many substances when heated emit electrons. Ultraviolet radiation and even visible rays when falling on substances, for example, a zinc plate, cause electrons to be emitted by the substance. The conduction of electricity through metals may be considered a migration of electrons more or less free to move. Electrons are expelled from atoms in such a case as radioactivity. These are only a few of the many activities of electrons. It should be obvious that in some cases the electrons are associated with the atom as an element, thereby aiding in determining the physical and chemical properties of the atom. Some of these electrons are easily displaced from the atom and likewise readily return. In other cases, such as radioactivity, electrons seem to be very intimately a part of the atom. When one of these is lost by spontaneous emission the atom is altered irrevocably. It has become another element.

In still other cases, we might think of more or less free electrons throughout the substance. These different degrees of "attachment" might be considered to be determined by the position of the electron in the atom. If there are electrons bound up in the nucleus, these would likely be displaced with the greatest difficulty. Those in rings revolving about the nucleus might be more readily displaced. This is merely a temporary suggestion to give the reader a helpful picture.

In modern theory, the nucleus of the atom consists of electrons and protons bound together. However, they may differ in number and, therefore, this difference would be the apparent charge on the nucleus. One proton will neutralize one electron so that the excess of protons, for example, will determine the positive charge of the nucleus of an atom. Inasmuch as the mass of an electron is inappreciable relative to that of a proton, the relative mass of an atom (atomic weight of an element) is determined by the total number of protons in the atom. Thus atoms may have the same chemical properties (dependent largely on the nuclear charge) and still have different atomic weights. This accounts for the isotopes discussed in Chapter VIII. Incidentally, the word *isotope* is derived from the Greek, meaning the *same place.* Isotopes of an element occupy the same place as the element in the periodic table, because they have identical chemical properties notwithstanding the difference in their atomic weights. The positive charge of the nucleus of an atom is indicated by the atomic number; that is, there are as many unneutralized protons as indicated by the atomic number. How many electrons revolve around this nucleus is discussed later. Here we are interested chiefly in the fact that the combination is the atom.

The scattering of a shower of missiles will depend upon the number, size, and mass of the objects encountered by the missiles. Experiments with various minute missiles in which

the components of atoms were the objects which caused the scattering, indicate that there are about half as many electrons in the atom as its atomic weight. However, it seems that the number of electrons in an atom at least should equal its atomic weight. If the nucleus of a hydrogen atom is a proton, one electron should be associated with it in order to neutralize the electric charge. In the case of helium, whose nucleus possesses an unbalanced charge equivalent to 4 protons, 4 electrons must be associated with it to neutralize it. Therefore, if experiments indicate that electrons equivalent to only one half the atomic number will account for the scattering, about the same number must be present in the nucleus in order to have the nuclear charge neutralized.

Thus we would have *external* and *nuclear* electrons. Modern theory does consider both regions as the habitat of electrons. The question arises, Why do not these nuclear electrons scatter the minute missiles just as effectively as if they were located external to the nucleus? The answer is that they may be greatly reduced in size when packed into the nucleus. We should not forget that we are dealing with electric charges possessing *electric mass* and (why not?) *electric size*. It is conceivable that such an ethereal thing could shrink along with a proton. When an electron and a proton neutralize each other's charge is it inconceivable that they neutralize each other's size? Here is something for the imagination. Discussions of the actual theories of atomic structure clarify some of these aspects of the atom.

Chapter XII

THE QUANTUM OF ENERGY

Ever since the wave theory of light was propounded by Huygens over two centuries ago it has been assumed that the wave-front was continuous. The radiant energy was supposed to flow in a series of waves in all directions from the source. When Maxwell developed the idea that light-waves were electromagnetic in character and belonged to a great family of electromagnetic waves differing only in wavelength, no modification of this idea of continuity and homogeneity was made. At any instant in any portion of space through which radiant energy was passing, the hypothetical ether was supposed to contain a certain amount of energy. On this basis a body, such as a light-source or a heater, emitted radiant energy continuously which flowed in all directions like a perfect homogeneous fluid. By virtue of this spreading, the intensity of the radiant energy at any point, or the quantity passing through a given area, decreased with distance. The inverse-square law is well known. For example, the intensity of illumination at a certain distance (the quantity of light per unit area) varies inversely as the square of the distance and, of course, directly as the intensity of the light-source.

The present outlook is quite different although it does not alter the chief principles or laws of radiant energy which have been determined from experimental data. However, the new theory has done wonders in explaining many accumulated data and in predicting physical phenomena. This theory is the result of the atomistic principle applied to the processes of

radiation. We have seen the wonderful achievements of atomism in various ways. It seems fortunate that Nature constructs just as we human beings do — with "bricks." The atom is built of protons and electrons and molecules are built of atoms. Matter and energy are the structural materials of the universe and they are built of "bricks." If energy is radiated by components of the atom, it is just as logical to think of this energy emitted discontinuously — in elementary quanta — as continuously. In fact, our human experience is better satisfied with the idea of "atoms" of radiant energy than with a continuous flow of such energy.

A Preliminary View

According to the quantum theory of radiant energy, which was founded by Planck in 1900, the atom radiates energy in small units which are definite and irreducible. The intensity of the radiant energy depends upon the rate of emission of these *quanta*. The magnitude of these elementary quanta depends upon the wavelength or frequency of the radiant energy. This elementary "atom" of energy is not of the same magnitude for all electromagnetic waves. Its magnitude is the product of a certain universal constant h and the frequency n of the radiant energy. This constant is unalterable. It applies to the physical process. It has been termed *the elementary quantum of action.* The "atoms" of energy vary in magnitude in proportion to the frequency of the energy because each of these "atoms" or quanta of energy, as already stated, is the product of the constant (or quantum of action) and the frequency. Thus, the elementary energy quantum of blue light is nearly twice as large as that of red light because the frequency of the former is nearly twice as great as that of the latter.

Planck determined the elementary quantum of action which is termed *Planck's constant*. If we designate it by h and the frequency by n, the quantum of energy of any particular frequency n is equal to hn. The quantum theory was destined to be far-reaching. Although it was first applied to the laws of radiation from hot bodies, it was soon invading many realms of physics. From his mathematical equations Planck was able to determine a number of physical constants such as h, the mass of the hydrogen atom, and the elementary quantity of electricity.

Einstein developed the *theory of light-quanta* and applied the quantum theory to various physical phenomena, such as photoelectric effect and fluorescence. Later the idea was applied to the theory of specific heat of bodies. The quantum became an important factor in the development of theories of atomic structure. A quantum theory of spectra of great promise arose and it is brilliantly fulfilling that promise.

When one contemplates the great importance of radiant energy (light, X-rays, gamma-rays, electric waves, etc.), the intimacy with which it is woven into physical processes and its fundamental place in the scheme of the physical world, it it obvious that an atomistic view of it, if substantiated by experiment, is very far-reaching. In fact, few realms of physics escape the influence of the quantum theory.

The Quantum of Energy

One of the valuable products of the quantum theory is the actual determination of important physical constants and magnitudes. These are not only interesting in themselves, but some of them aid us in understanding clearly what the quantum means.

Plank's constant, h, equals 6.55×10^{-27} erg-seconds.

An erg is the work done by a force of one dyne acting through a distance of one centimeter.

A foot-pound or a force of one pound acting through a distance of one foot is equal to 1.35×10^{7} ergs or 13.5 million ergs.

The quantum of energy for radiation of any frequency n is equal to hn. For example, the frequency of red light is 390 million million cycles per second, that is, 3.9×10^{14} cycles per second. Therefore, the quantum of energy for red light is,

$hn = (6.55 \times 10^{-27})$ times $(3.9 \times 10^{14}) = 25 \times 10^{-13}$ ergs.

The frequency of violet light of the shortest wavelength which causes visual sensation is about 770 million million cycles per second, therefore, the quantum of energy for radiant energy of this wavelength is,

$hn = (6.55 \times 10^{-27})$ times $(7.7 \times 10^{14}) = 50 \times 10^{-13}$ ergs.

The quantum of energy for ultraviolet radiation having a frequency of 31×10^{14} cycles per second is,

$hn = (6.55 \times 10^{-27})$ times $(31 \times 10^{14}) = 200 \times 10^{-13}$ ergs.

Ultraviolet radiation of this frequency is not transmitted by ordinary glass. It is near the limit of transmission of quartz and even of air.

The quantum of energy of Röntgen rays having a frequency of 31×10^{17} cycles per second is,

$hn = (6.55 \times 10^{-27})$ times $(31 \times 10^{17}) = 200{,}000 \times 10^{-13}$

Gamma rays from radioactive elements are of still greater frequency than Röntgen rays so that their quanta of energy are still greater.

Thus, it is seen that we have an "atom" of energy — a quantum — but it is not constant. Its magnitude depends directly upon the frequency of the radiant energy. Inasmuch as the frequency is proportional to the reciprocal of the wavelength, the quantum of energy in any case is proportional to h divided by the wavelength.

The relative magnitudes of the quanta of energy as computed in the foregoing are as follows:

Red light	1
Violet light	2
Ultraviolet	8
X-rays	8000

Gamma rays still greater.

It should be understood that the wavelengths or frequencies of ultraviolet, Röntgen, and gamma radiation extend over a considerable range. Those used in these computations were selected arbitrarily for the purpose of giving the reader an idea of the relative magnitudes of quanta of energy.

From the magnitude of a foot-pound it is seen that the amount of energy which must be expended to raise a pound weight a height of one foot is equivalent to

1.35×10^{7} divided by 25×10^{-13} or
5.4×10^{18} quanta of red light or
5.4 billion billion quanta of red light.

The number of quanta of violet light required to do the same amount of work, that is, to raise one pound a height of one foot, would be half as great; and so on, as indicated by the data already presented.

There should be no difficulty in grasping the idea of a quantum of energy. The fact that it is variable, that is, dependent on the frequency is logical. Atomic weights are different for different elements. We might use this as an analogy. Energy of a certain wavelength or frequency is just as characteristically different from energy of any other frequency as an atom of one element is different from that of another element. Atoms of elements are made up of the same "material," but differ only in the amount of material and consequently in atomic number

and atomic weight. "Atoms" of radiant energy — quanta — may be considered to be analogously constructed; that is, they all consist of the same "thing" but in more or less quantity. They are distinguished from each other by their rate of vibration or frequency. To our senses their characteristic difference is that of frequency which also determines the amount of energy per quantum.

It may also aid in visualizing the quantum to return to the term *force*. Newton invented *force* to relate two physical realities — mass and acceleration. Force was not a reality. It was not proved to exist. It exists in our minds merely as something which alters the motion of a body. The motion and the body are realities in terms of which we define the invention — force. Somewhat analogous to force is Planck's constant *h*. Certainly a quantity of energy is a reality and likewise frequency is a reality. They are so related that *h* is a constant. This *h* may be termed *a quantum of action* or *a unit of a process* or anything reasonable, but it still remains an invention performing a function analogous to *force* — it relates two realities.

Photoelectric Effect

Hertz, who produced for the first time experimentally the electromagnetic waves which Maxwell had predicted in theory, discovered in 1887 that ultraviolet radiation incident upon a spark-gap decreased the voltage necessary for the passage of a spark. In other words, the conductivity of the air between the terminals of the gap was increased in some manner by the ultraviolet radiation. Now this is easily explained by the ionization of the air; that is, by the formation of ions and electrons, but it will be recalled that in those years little was known of the electron. It was soon learned that ions and electrons were produced by ultraviolet radiation and Hallwachs began a sys-

tematic study of the phenomenon. He insulated a clean zinc plate electrically and permitted ultraviolet radiation to fall on it. He found that it gradually acquired a positive charge which increased with time and with the intensity of radiation. This positive charge could be the result of positive electricity being added to the zinc plate or of negative electricity leaving it. He then charged the plate negatively and found that it lost this charge when ultraviolet radiation fell upon it. He concluded from further experiments that electrons (negative) were dislodged by the radiation.

Many metals were found to exhibit this *photoelectric effect.* Even molecules of liquids and gases gave up electrons under the influence of ultraviolet radiation. In fact, a great variety of substances exhibited this phenomenon and various applications of it have been made. For example, the *photoelectric cell* is now used to measure intensity of radiation. The magnitude of the phenomenon depends not only on the substance, but also on the wavelength (or frequency) and intensity of the radiant energy. Relatively little effect is produced by red and yellow light with most substances. In general, the effect is greater for blue light and radiant energy of shorter wavelengths or higher frequencies. Ultraviolet radiation, Röntgen rays and gamma rays produce the effect.

A closer study of the photoelectric effect revealed the fact that the kinetic energy of the expelled electrons was independent of the intensity of the radiation (quantity of radiant energy per unit area.) The number of them merely increased when the intensity of radiant energy was increased. The kinetic energy was found to depend upon the frequency (or wavelength) of the radiant energy. Inasmuch as the mass of the electron is practically constant for the velocities involved, the velocity of the emitted electrons may be said to depend on the frequency of the radiant energy. (It will be recalled that kinetic

energy is equal to one half the product of the mass of a body and the square of its velocity.)

Doubtless the reader immediately sees a possible explanation on the basis of the quantum theory. Certainly Einstein did, for he proceeded to the development of the theory so as to explain photoelectric effect. Inasmuch as the velocity possessed by the electrons, as they left the substance, was constant for any given frequency of radiation, one is led to suspect that each electron is expelled by " kicks " or " shocks " of the same magnitude. This is explained by assuming that each electron absorbs a quantum of the incident radiant energy. The kinetic energy possessed by an electron as it leaves the surface is less than the radiant energy absorbed by the amount of energy expended in breaking away from its atomic habitat.

It will be recalled that the quantum of energy is the product of a constant h and the frequency n. In other words, the quantum increases with the frequency. The kinetic energy of the emitted electrons was found to be proportional to the frequency. Thus, it is seen that the quantum theory of radiant energy explains this phenomenon very well. Einstein extended Planck's original theory to explain photoelectric effect and his mathematical equations nicely predicted this relation of the kinetic energy of the emitted electrons to the frequency of the incident radiant energy, and, therefore, to its quanta. Just as the quanta are assumed to be emitted in entire units, so are they assumed to be absorbed. An atom is assumed to be incapable of emitting a fraction of a quantum and, likewise, an atom or electron is incapable of absorbing a fraction of a quantum. An egg is an egg no matter how large or how small. It is produced as an entity. So it is with the quantum. But here the analogy ceases, for any portion of an egg can be absorbed by absorbers of eggs. Quanta of energy are absorbed only in their entirety.

Millikan conducted an elaborate investigation of the photoelectric effect and by determining frequencies of the radiation and the kinetic energies of the expelled electrons obtained a complete verification of the predictions of Planck and of Einstein based on the quantum theory. From these investigations the Planck constant h has been accurately determined.

Fluorescence

For many years it has been known that some substances, after being illuminated by light and various other electromagnetic radiations, will glow in the dark for a long time. This long-period glow is termed *phosphorescence*. It is not a chemical phenomenon; it is purely a physical one involving the displacement of electrons temporarily. There is a short-period glow which is termed *fluorescence*. This is the glow which persists only while the substance is being subjected to the "exciting" radiation. Visible radiation, ultraviolet radiation, Röntgen rays, and gamma rays produce these effects although in general, radiant energy of higher frequency (or shorter wavelength) than blue light is the most effective. Like the photoelectric effect, the magnitude of these effects depends on the substance and on the frequency of the incident radiant energy. If examined closely enough, nearly every material will exhibit the property of fluorescence at least feebly. In some cases, radiant energy of lower frequency, such as infrared, quenches the phosphorescence speedily and effectively.

One of the peculiarities of this phenomenon which has been known for a long time is that the radiation emitted by fluorescent substances is always of lower frequency than the frequency of the radiant energy which excited the fluorescence. This is known as *Stokes' law* after the discoverer. It will be noted that the phenomenon of fluorescence is really a trans-

formation of radiant energy from a higher frequency to a lower one. Röntgen rays will cause some substances to glow visibly. Gamma rays and ultraviolet radiation produce similar effects.

It will be recalled that alpha particles (helium atoms with a double charge) and also positive rays (such as hydrogen ions) produce splashes of light when they strike a fluorescent screen. Here we have light produced by particles in motion. Röntgen rays are produced by cathode rays (electrons moving with high velocity) striking the "target" of the X-ray tube. The atoms of this target emit Röntgen rays. These are examples of the transformation of the kinetic energy of moving masses into radiant energy. Photoelectric effect is quite the reverse phenomenon, being a transformation of radiant energy into kinetic energy — moving masses (electrons).

Einstein extended the quantum theory so that it explained these phenomena— this interchangeability of energy. Planck had first confined the original idea of the quantum of energy to the emission of radiation from hot bodies. He dealt with the process of emission of radiant energy. Einstein assumed that radiant energy is actually propagated in quanta. That is, Planck developed the idea that radiant energy is emitted in units or quanta, but Einstein developed the theory of light-quanta actually retaining discrete units of energy even when passing through space and matter. Thus we see that Newton's emission-theory idea is revived, but on an entirely different foundation. The predictions of the extended quantum theory have been verified in many ways. According to the theory, radiant energy is transferred to the electron if the frequency of this electromagnetic energy is sensibly near to the natural period of vibration of the electron. Inasmuch as a quantum is absorbed by an electron only in its entirety, it should be obvious that the emitted radiation in the case of fluorescence cannot be of higher frequency than that of the energy which excites

the fluorescence. The magnitude of a quantum of energy depends upon the frequency. An emitted quantum cannot be larger than the exciting quantum. Thus, if an electron absorbs a certain quantum, it cannot emit a larger quantum, so that in the case of fluorescence, the frequency of the emitted quantum cannot be greater than the frequency of the absorbed quantum. Similarly, in the case of the photoelectric effect, the kinetic energy of the emitted electron cannot be larger than the quantum which expelled the electron. In these transformations from kinetic to radiant energy and vice versa, it is conceivable that there could be losses of energy not necessarily accounted for by disappearances of a fraction of a quantum. The loss could be explained by the appearance of a smaller quantum (lower frequency) or of a kinetic energy equivalent to a smaller quantum than that at the beginning of the event.

Laws of Radiation

It is hoped that the preceding paragraphs have given the reader a definite idea of what is meant by a quantum of radiant energy. The phenomena of fluorescence and photoelectricity were discussed from the viewpoint of the quantum because they serve very well in illustrating how the quantum operates. However, in presenting these phases of the subject it was necessary to touch upon Einstein's extension of the quantum theory several years after Planck propounded the idea. We will now return to Planck's original work in 1900 when he originated the quantum idea for the purpose of explaining the processes and laws of radiation emitted by hot bodies.

The laws of radiation from hot bodies deal first with the so-called *black-body*. It is a theoretically perfect radiator. Such a body absorbs completely radiant energy of all wave-

lengths or frequencies and also when heated emits radiant energy of all wavelengths or frequencies in maximal amounts. The *emissive power* of a black-body depends only on its temperature. This is not true of any other body which is not a *black-body*. The opposite of a black-body is one that is perfectly reflecting. If a piece of carbon and one of nickel are heated electrically in a vacuum to the same temperature, the carbon will be brighter than the nickel. In other words, its emissive power is greater than that of the nickel. In this respect we should not make the error of considering that a non-black-body necessarily retains the same absorbing and reflecting characteristics at high temperatures that it has at ordinary temperatures. Its property of reflecting or of absorbing light may vary considerably with the temperature. Nevertheless, it is true that most bodies are still imperfect absorbers at high temperatures and, therefore, are imperfect radiators. Being imperfect radiators (of lower emissive power than a black-body) they emit less radiation per unit area than a black-body does at the same temperature. The black-body idea was originated in order to obtain a fundamental relation of temperature in the laws of radiation. Inasmuch as space does not permit us to discuss the properties of radiators in general, we will confine our interest to the theoretical black-body. Carbon is a practical example sufficiently approaching a black-body for many purposes.

Stefan in 1879 discovered that the emissive power of a black-body depends upon its temperature. Several years later Boltzmann developed the mathematical theory which related these two factors. This *Stefan-Boltzmann law* states that the *emissive power of a black-body is proportional to the fourth power of its absolute temperature.*

$$\text{Emissive power} = k \ (\text{absolute temperature})^4$$

Thus the ratio of the emissive power to the fourth power of

absolute temperature is equal to a constant k. This is termed *Stefan's constant*.

Let us now consider the characteristics of the radiant energy emitted by a heated black-body. For our purpose we will assume a carbon filament to be a black-body (it is approximately) and we will heat it electrically as in a carbon-filament electric lamp. If we pass an electric current through it, however small, it will begin to radiate energy — electromagnetic waves. Even though it may not feel warm, it is emitting electromagnetic waves of long wavelengths or low frequencies. These are *infra-red radiations*. If we increase the temperature, the filament will begin to feel warm, but notwithstanding the fact that it still does not glow, it is radiating infra-red radiation. We do not see it glow because it has not reached a temperature at which it emits radiation of short enough wavelength to produce the sensation of light. Our eyes are not "tuned" for these longer wavelengths, but we may readily imagine eyes that do respond to such radiations. Probably they do not exist in the animal kingdom, but physical eyes can be made in the laboratory to respond (and appraise or measure) radiant energy of any wavelength.

When we have increased the current sufficiently to raise the temperature of the filament to about 1000 degrees Fahrenheit, we note that the filament glows feebly, a dull red. Among the radiations now emitted are some of high enough frequency to cause the sensation of red. As we increase the temperature still further, radiations of higher and higher frequencies are produced along with all those produced at lower temperatures. The color of the filament passes through orange and yellow. Now we must assume that this filament remains solid for very high temperatures (which it actually does not.) If we continue to raise the temperature, radiations of higher and higher frequencies appear. Soon radiations of all frequencies

to which our eyes respond are present. The filament appears white and then blue-white. We see only the *visible radiation* and, if we form a spectrum by means of a glass prism or a diffraction grating, we see a continuous spectrum exhibiting many colors, including red, orange, yellow, green, blue, and violet. At a high temperature, if our eyes responded to the radiations of all frequencies, we would see a continuous band from the far infra-red through the visible and ending far into the *ultraviolet* regions.

Although our eyes do not record the presence of all these radiations, we can make physical eyes in the laboratory which

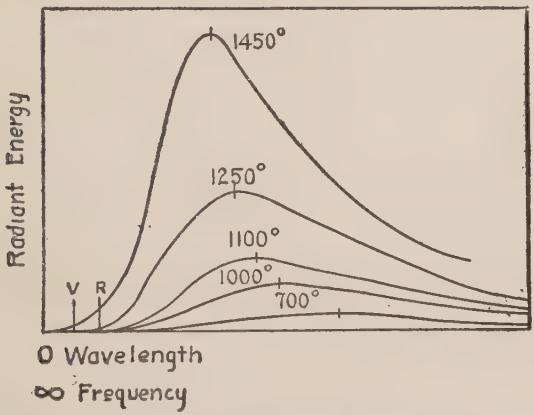


FIG. 14. These curves illustrate the relative amounts of radiant energy of various wavelengths or frequencies emitted by solid carbon at various absolute temperatures. It is seen that the wavelength of maximum emission decreases as the temperature increases. The limits of the visible spectrum are shown by *V* (violet light) and *R* (red light). No radiant energy of wavelengths within this region is emitted by the solid carbon at temperatures below about 900 degrees absolute.

do. In this way we can determine the amounts of radiant energy of each wavelength or frequency emitted by the blackbody at various temperatures. This spectral distribution of energy of various frequencies differs with temperature as

shown in Fig. 14. It is seen that the frequency of maximum energy shifts toward higher frequencies as the temperature increases. The frequency or wavelength at which the emissive power is greatest, Wein, in 1893, noticed was proportional to the reciprocal of the absolute temperature. Stated in another way, the product of the wavelength of maximum emissive power and the absolute temperature is constant. This is known as *Wein's displacement* law and may be represented thus,

$$\lambda_m T = \text{constant}$$

$$\frac{T}{n_m} = \text{constant}$$

where λ_m is the wavelength and n_m is the frequency of radiation emitted in greatest quantity (maximum emissive power) for a given absolute temperature T. The constant is termed *Wein's constant* and is equal to 0.294 centimeter-degrees K.

The establishing of this *displacement law* was one of the foundations upon which the theory of radiation was built. The two laws already presented deal only with specific parts of the problem of radiation. A general law was still necessary which related frequency, temperature, and intensity (or quantity) throughout the entire range of frequencies from the extreme ultraviolet to the extreme infra-red and for any temperature. Wein developed such a relationship, but it stood the test of experiment only for the region of shorter wavelengths or higher frequencies (ultraviolet and short-wave portion of the visible spectrum) and for a range of relatively low temperatures. Rayleigh developed another law which was experimentally valid only for the region of long wavelengths (infra-red) and for relatively high temperatures. This was the situation until 1900 when Planck propounded the quantum theory for the purpose of deriving a general law of radiation which showed the true relation of frequency and intensity of

radiation for all temperatures of a black-body radiator. In other words, his law of radiation gives us the spectral distribution of energy throughout the entire spectrum or range of frequencies for all temperatures in a way that is in satisfactory agreement with experimental data.

The Quantum Theory of Radiation

We are already familiar with Planck's elementary quantum of energy. It is sufficient for us to conceive of these entities of energy emitted by the electrons in the atoms due to some kind of temporary displacement of the electrons or disarrangement in the atomic systems. In the case of a gas or a vapor which is emitting radiation, the electrons by some means have been displaced and it is assumed that when they return radiation is emitted. This acceleration or change is responsible for the emission of quanta of energy. In a gas or vapor the atoms are relatively free and the vibrations of the electrons and nuclei are of their natural period. Therefore, the spectra of the radiation from these relatively free atoms are characteristic of the element. Spectral lines are the result. (See Fig 10.)

In the case of solids, the atoms are relatively close together. Their movements are now a part of a "mob." They are not independent. They are jostled and their vibrations are dampened and interfered with. They can no longer vibrate at their natural period and, therefore, cannot emit the characteristic frequencies (spectral lines) of the elements which they represent. The spectrum of a hot solid (or liquid) is continuous. Radiations of all frequencies which the particular temperature is able to produce are represented as discussed in other paragraphs.

As already stated, no theory of radiation existed prior to

Planck's effort, which was completely in accord with experimental data. Planck directed his attention to the process of radiation. He looked into the atom. Previous theory was based on the assumption that the atomic radiators or oscillators which emitted the electromagnetic waves did so by a continuous process. That is, the interchange of energy between the atomic radiator and the ethereal space around it was achieved through a succession of infinitesimal amounts. Planck could not account for the spectral distribution of energy in this manner. It will be noted that the forms of the curves in Fig. 14 are similar to the probability curve; that is, to the curve showing the probability of the emission of energy of various wavelengths. In the kinetic theory of gas we have a similar situation. The velocities of individual molecules at any instant vary from zero to a maximum. In a solid radiator we have similar probabilities of vibration of the atomic oscillator which emits the radiation. Planck was able to develop a law mathematically which gives the probability of an oscillator emitting energy only when it possesses energy equal to a quantum or multiples of it.

It is out of the question to follow Planck through his assumptions and equations. In fact, this would only lead us to the fact that, by assuming the emission of quanta of energy which vary in magnitude with the frequency, he developed a law of radiation which is in agreement with experimental data. This had never before been achieved.

Other Consequences

We have already had glimpses of the far-reaching effects of the quantum idea. Throughout modern physics it has made itself felt. Einstein extended the quantum theory to the specific heat of solid bodies. The specific heat of a body is

the amount of heat necessary to raise the temperature of one gram of the substance one degree Centigrade. A century ago Dulong and Petit discovered that the product of the specific heat of a body and its atomic weight was constant for nearly all elements in their solid state. This product is termed the *atomic heat.* However, there were exceptions to this law which were never explained until Einstein applied the principle of the quantum of energy. According to the kinetic theory of heat, the temperature of a body is due to vibrations of the molecules or atoms. Of course, the statement may be reversed if desired. Einstein added to this the assumption that the energy of these atomic vibrations existed as quanta whose magnitude depended on the frequency. The mathematical results, which he obtained by introducing this hypothesis, explained the variations from Dulong and Petit's law. At low temperatures the average vibration of atoms of a solid is small. On the basis of the quantum theory only a small percentage of the atoms contain quanta of energy. Inasmuch as it is assumed that the atom holds "all or none" of a quantum, it is seen that most atoms at this low temperature are unable to hold a quantum of energy. Therefore, they cannot absorb energy under these conditions and the specific heat of the body approaches zero. This is in accordance with the facts of experiment, thereby lending support to the quantum theory as applied to theory of heat.

The quantum theory gradually established itself throughout the realm of radiation from hot bodies, of photoelectricity, of fluorescence, and of heat. Inasmuch as these phenomena may be traced to the atom, it was inevitable that the quantum would play a major rôle in modern theory of atomic structure. In 1913, Bohr introduced the quantum into Rutherford's theoretical atom and as a result a new theory of spectra and of the structure of the atom resulted. Although the quantum

theory is relatively new and all the details of the process of radiation and absorption of quanta are not clear, this theory and the extensions of it have enjoyed many brilliant successes in various branches of physics. Naturally other modern views such as the principle of relativity have been interwoven with it so that it is difficult to consider it separately. Many of these views have converged upon the atom with the result that the phase of physics known as atomic structure has been given a great deal of attention recently. Without the aid of mathematics we cannot go very deeply into some of these subjects. Furthermore, it has been the aim to present correlated glimpses of many phases of physics without introducing too many ideas which are not generally accepted or supported by experimental data.

Chapter XIII

ATOMIC STRUCTURE

In devising atomic structures, science is confronted with the task of relating the smallest known masses or charges of electricity with highly potent manifestations of energy. What a saving in time would be achieved if we could direct a super-microscope upon the atoms of elements and see what is going on within them. Instead, scientists must grope more or less blindly, guided only by the manifestations of the atoms. Rutherford and others bombarded the atom with swiftly moving missiles of atomic and sub-atomic magnitudes. This is an example of direct attack. However, most of the work on the atom begins with interpretations of the electromagnetic waves which the atoms are emitting.

Suppose we detected colored light-signals or other electromagnetic waves emanating from our neighboring planet Mars, which were such that they were obviously "artificially" produced. They would be in an unknown language developed by beings of which we know nothing. We would try to interpret them in terms of our experiences, but doubtless, these signals would tax our imaginations to the utmost for a long time. Various interpretations would be advanced at first. These would be modified many times. Impossible as the task might seem, it is likely that we would eventually arrive at an understanding. At least, we have in common with our hypothetical neighbors on Mars, the foundations of the universe. We are certain that the elements and their combinations, fundamentally physical phenomena, and the same foun-

dational scheme of Nature exists for them as for us. The beings themselves, if they exist, would probably be quite different from Earth-beings. It would tax the most active imagination to picture their possible appearance, mode of life, and even their needs for sustaining life.

With the atom we have an analogous situation. Of course, we have some slight knowledge of the electron and the proton. We know they exist and it seems certain that they are vital parts of the atom. We have never seen them. We say vaguely that they contain electric charges and even that they *are* electric charges. Like *force* in Newton's laws electricity is an invention of ours to account for certain phenomena. Besides these meager data we must rely chiefly upon the signals which the atom is sending forth. For two centuries we have been recording the frequencies of these electromagnetic waves, but only for a half-century have we known that these are electromagnetic waves. By studying the records long ago, science learned that each element sends forth its own characteristic signals. (See Fig 10.) Gradually relationships were noticed. We have learned this "sign-language" of the spectra of elements as far as recognizing the elements. Recent developments promise to reveal the mechanism which sends the signals. Finally, through interpretation of these spectra we may hope to know all about the inhabitants of the atom and their relationships within it.

Spectra of Elements

Throughout these chapters we have seen that light-waves and other electromagnetic waves are very important factors in many natural processes. Therefore, any instrument which separates them into their various wavelengths or frequencies is a very important tool for the scientist. Such an instrument is the spectroscope. At the receiving end there is a fine slit

through which the radiant energy enters. Eventually this energy is dispersed by a prism or diffraction grating with the result that the beam of light, which here means radiant energy of any frequency, is spread out into a fan-shaped beam. Light of greatest frequency is bent more from the direction of the path of the original beam than light of lower frequency.

The spectra of some elements consist of radiant energy of relatively few different frequencies and, if we permit the spectrum to fall on a ground glass or a white surface, we will see colored lines which are images of the slit of the instrument. (See Fig. 10.) These lines are separated according to wavelength or frequency so that, if we have a scale properly prepared, we can read from it the frequencies of radiant energy emitted by the element under consideration. This accounts for the origin of the term *line spectrum*. Inasmuch as radiant energy of only a limited range of frequencies excites visual sensation, we must use the photographic emulsion or other physical "eyes" when we desire to record the invisible radiant energy. To extend studies into the extreme ultraviolet, X-ray, and gamma-ray regions, the ingenuity of the scientist has been hard pressed.

The spectra of elements differ very greatly. Some of them contain only a few lines, others contain thousands of them. Still no two are alike. These spectra are so different and each is so characteristic that, from the line-spectrum of a far-off star, it is a comparatively simple matter to ascertain what elements are signalling to us across that inconceivable distance. A complication arises in spectroscopy due to the fact that the spectrum of an element depends somewhat upon the manner in which the atoms are excited to radiate energy. The line-spectra are emitted only by gases and vapors so that solid elements must be vaporized by high temperature. In the laboratory this is done in a gas flame, in an electric arc, and

in various other ways. Owing to the very high temperature of the sun and other stars, the elements are vaporized. However, the spectrum of any element in general will differ somewhat with the density of the vapor, but these differences which have been mentioned are not such that one element can be mistaken for another. They are chiefly in the number of lines (frequencies of radiant energy) present. The lines that are present in any case are always characteristic of the element emitting them.

Some very important relationships of spectral lines or frequencies of radiation have been detected and these are playing important parts in present attempts to fathom the structure of atoms. For example, Balmer, in 1885, found that the lines of the hydrogen spectrum are related in a very systematic manner. If this is true then there is a systematic relation in the sources within the atom which are responsible for the emission of these radiations of various frequencies or wavelengths. Balmer was able to find empirically a simple mathematical equation from which the wavelengths of a series of hydrogen lines could be calculated. The derivation of an exact mathematical equation was not achieved until Bohr recently applied modern theory to the atomic structure which he had devised. It is now known that there are three distinct line-series in the hydrogen spectrum and that such relationships exist in the spectra of other elements. The *Balmer series* for hydrogen may be computed from the following relationship:

$$\text{Wavelength in cm.} = \frac{M \times m^2}{m^2 - 4} \times 10^{-8}$$

where M is a constant equal to 3646.14 and m is successive integers of a series 3, 4, 5, 6, etc. By substituting successive values of 3, 4, 5, 6, etc., for m, one obtains the successive wavelengths of the Balmer's series of hydrogen lines.

Over thirty lines in this series have been recorded in the spectrum of hydrogen in certain tenuous nebulae of the heavens. Until recently the twelfth line has been the limit produced in the laboratory; however, recently Wood recorded twenty of these lines for hydrogen electrically excited in a vacuum tube. Bohr's theory of atomic structure accounts for the Balmer series very nicely by assuming that the different spectral lines are produced by radiation emitted by electrons rotating in orbits of different diameter. The greater the number of spectral lines (frequencies), the greater is the maximum diameter of the electronic orbits. Obviously the atom must occupy a space sufficiently large to accommodate its largest possible electronic orbit. Therefore, the density of the gas must be small in order to obtain many hydrogen lines. This is true in the so-called electric discharge tube and in the celestial nebulae, which is in accord with the large number of the spectral lines recorded in these cases.

What has been stated of the hydrogen spectrum is also true for the spectra of other elements. Hydrogen was chosen for discussion because it is a simple atom and usually is the starting point of theories of atomic structure.

A few years after Balmer made his important discovery of the simple numerical relations among spectral lines of hydrogen, Rydberg extended this idea. He discovered the following simple relation,

$$R\left\{\frac{1}{a^2}-\frac{1}{b^2}\right\}=n=\text{frequency}$$

R is known as the *Rydberg constant* and is equal to 3290×10^{12} or 3290 million million. For computing the frequencies of any given series *one* of the numbers, 1, 2, 3, 4, etc., is substituted for b. The various frequencies of a given series are then determined by substituting *successively* the numbers 2,

3, 4, 5, 6, etc., while a remains constant. The series of spectral lines of hydrogen and of helium computed from this relationship are in close agreement with the frequencies determined by experiment. The Rydberg constant has been found to play an important part in the more complex mathematical equations which express certain regularities in the spectra of other elements. In fact, it has the earmarks of a universal constant. Haas in 1910 applied the quantum idea to the theory of spectra and found that the Rydberg constant is closely connected with Planck's constant h and with the mass and charge of the electron. Incidentally, Bohr was able to evaluate the constant R on the basis of his theory of atomic structure.

The Thomson Model

It will be recalled that the atomic model suggested by J. J. Thomson marked the beginning of attempts to construct atoms of electrons and positive electricity. The positive part of his model was a sphere about the size of the atom itself containing a total positive charge of sufficient amount. Its radius was about ten billionths of a centimeter. The electrons were in stable symmetrical arrangements. The electrons remained in their normal positions unless displaced by some force. Emission of light was considered to be due to oscillations of these electrons resulting from the more or less "elastic" restoring force which pulled them back after they had been displaced. This model served very well in many ways and a great deal of theoretical optics was built upon it. However useful it was, it did not account for Balmer's series satisfactorily. Its nucleus (if such it could be termed) was the sphere of positive charge and this was as large as the atom itself. This was incompatible with the results obtained for the scattering of alpha particles with which Rutherford,

Marsden and others bombarded hydrogen and other atoms. This scattering was not great enough to account for such a large sphere of positive electricity. In fact, it called for a very small nucleus because the alpha particles were shown to approach much closer to the center of the hydrogen atom than ten billionths of a centimeter. This model also failed to explain certain optical phenomena which were discovered subsequent to its conception.

The Rutherford Model

The demand for a small nucleus which arose from the bombardment of atoms by means of alpha particles led Rutherford to construct a new model. The positive nucleus was assumed to occupy a very small space and to consist of one or more units of positive charge (protons) depending upon the element. The number of protons in the nucleus for any atom was equal to its atomic number as shown in Chapter VIII. Thus the nucleus of the hydrogen atom consisted of one proton; helium two protons; oxygen eight protons; and so on. Around this nucleus electrons were assumed to revolve in planetary orbits like the circular orbits which Copernicus assumed for the planets in our solar system. Later elliptical orbits were introduced analogous to those which Kepler found actually to be the case for the planets revolving around the sun. When the atom was electrically neutral there was assumed to be as many electrons revolving around the nucleus as there were unneutralized protons in the nucleus. The hydrogen atom in its natural state consisted of one electron revolving around one nuclear proton. The helium atom consisted of two electrons and two protons. Later experiments seem to indicate that protons are actually nuclei of hydrogen atoms. In this atom the rate of revolution of the electrons is proportional to the

energy of the atomic system. According to the electron theory an electron revolving at the rate of n revolutions per second emits electromagnetic energy of a frequency n. However, when the system loses energy by radiation its frequency of revolution should decrease and the frequency of the radiant energy should decrease. This would mean that we could not obtain sharp spectral lines. However, we do and therefore, a modification is necessary.

The Bohr Model

The previous models had evoked great interest. Much discussion brought forth the strong and weak points. They inspired many experiments which yielded new data. Planck had created the idea of the quantum of energy upon which to construct a law of radiation in agreement with experimental data. Bohr saw the Rutherford model in the light of new knowledge and its possibilities when linked with the quantum theory appealed to him. He set forth with new hypotheses. He assumed that the electrons must be confined to certain orbits which would enable them to emit only quanta of energy. He introduced the radical idea that when revolving in certain orbits the electron did not and could not radiate energy. By this means he overcame a serious defect in Rutherford's model, for in that model the continuous loss of energy would cause a continual decrease in the frequency of the radiation which it emitted. In Bohr's atom the electron can go on revolving forever in certain orbits without radiating energy. These orbits may be considered to be stable states and they may be designated as *quantum orbits*. Having eliminated the older idea of emission of radiant energy, Bohr had to devise some means for this. He did so by using Planck's quantum and assuming that the electron radiated only while passing

from one of the orbits to another. Its kinetic energy when revolving in one orbit is just one quantum larger than when revolving in another orbit. Therefore, in passing from the former orbit to the latter it radiates a quantum of energy. These assumptions may appear radical and empirical; nevertheless, the Bohr atom has met with great success in explaining many experimental data.

The most elementary diagram of the Bohr atom is shown in Fig. 15. The positive nucleus is assumed to occupy a

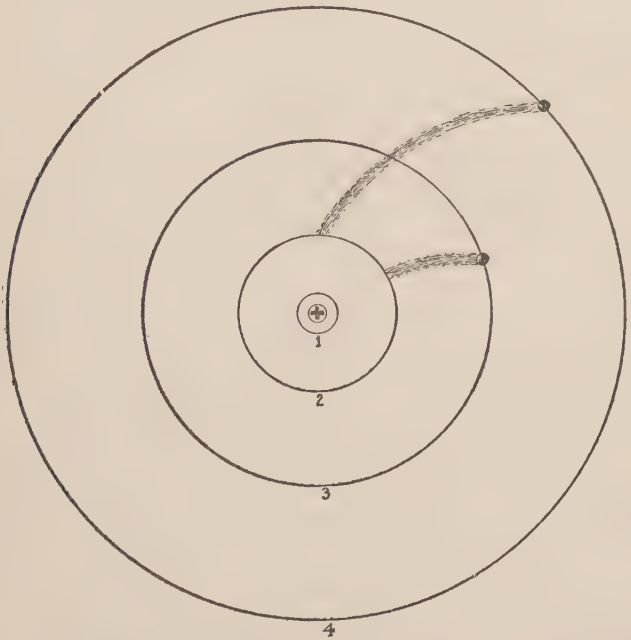


FIG. 15. According to the Bohr theory of atomic structure the spectral lines of hydrogen represented by the Balmer Series are produced by electrons of outer orbits falling into the two-quantum orbit. The radii of the various orbits are proportional respectively to the squares of their quantum-numbers. A four-quantum orbit has a radius 16 times that of a one-quantum orbit. A five-quantum orbit has a radius 25 times that of the one-quantum.

small space in accordance with the demands of the results of experiments involving the bombardment of atoms. The stable orbits or *quantum orbits* are indicated by 1, 2, 3, 4, etc. While revolving in these orbits the electron does not emit radiant energy; however, when it passes from 4 to 2, for example, it radiates a quantum of energy. When revolving in one of these stable orbits, the electron is assumed to be governed by the ordinary laws of mechanics, but these laws are assumed not to hold for the electron when jumping from one orbit to another. The kinetic energy of an electron revolving in any orbit is assumed always to be an exact multiple of the quantum of energy. We can think of the orbits 1, 2, 3, etc. as being respectively, one-quantum, two-quantum, three-quantum, etc., orbits respectively.

In each quantum orbit there is a definite value of the radius of the orbit, the frequency of revolution of the electron, the velocity of the electron, and the kinetic energy of the electron. The relationships of these are merely those of ordinary mechanics. For the one-quantum orbit the velocity of the electron is about 1330 miles per second or 140th the velocity of light; the revolutions per second are about 6 million billions; the radius is about five billionths of a centimeter; and the kinetic energy of the electron is the product of the quantum of energy and the Rydberg constant. There is a simple relation between these values and those for higher-quantum orbits. The energy of the electron in a two-quantum orbit is that in a one-quantum orbit divided by two squared; that is, it is one fourth of the energy of the electron when in the one-quantum orbit. In other words, the energy of the electron in any orbit is that of energy when in a one-quantum orbit divided by the square of the quantum number. The reverse is true of the radius of the orbits. The radius of the two-quantum orbit is four times that of the one-quantum orbit;

for the three-quantum orbit it is nine times, and so on. These values are presented herewith in terms of those for the one-quantum orbit.

RELATIVE VALUES OF RADIUS AND OF ENERGY

Orbit	*Radius*	*Kinetic Energy*
1–quantum	1	1
2–quantum	4	1/4
3–quantum	9	1/9
4–quantum	16	1/16
5–quantum	25	1/25
etc.		

Series of Spectral Lines

As already stated, Bohr's assumptions readily accounted for the simple relation between the frequencies of the Balmer-series of hydrogen lines and also of other series. This is done by assuming, in addition to the circular "*stable orbits* of the electrons, that the electron in its transit from one of these orbits, to another emits a quantum or radiant energy at the expense of one quantum of kinetic energy. In other words, we have a transmutation of kinetic energy into radiant energy (light, etc.) only in *discrete quantities*. It will be recalled that the difference between the kinetic energies of the electrons in these two orbits is equal to a constant (Planck's) multiplied by the frequency. Inasmuch as the kinetic energies of the electron in these two orbits are inversely proportional to the squares of the respective quantum numbers, it should be obvious that the frequencies of the emitted radiation in the two cases will be respectively represented by the differences between the two fractions. These two fractions will differ only in their denominators which are the squares of two whole

numbers respectively. This should be clear if the Balmer-series equation for hydrogen in a preceding paragraph is referred to. The frequency relation also connects Rydberg's constant to the magnitude of the hydrogen atom. From Bohr's theory of the atom the magnitude of the hydrogen atom is found to agree with determinations of it in other ways.

From Bohr's assumption, a spectral line is produced when an electron changes from one orbit to another. For each series there is an orbit which corresponds to the end of the series. For the Balmer-series the two-quantum orbit (Fig. 15) is the final one. When an electron jumps from a three-quantum orbit to the final two-quantum one, light of a relatively low frequency — a red spectral line — is produced. An electron jumping from a four-quantum orbit to the two-quantum one emits light of higher frequency — a blue spectral line. When it jumps from a five-quantum orbit to the two-quantum one, light of still higher frequency is emitted. By proceeding in this manner the Bohr model accounts for the ultraviolet spectral lines and for the entire Balmer-series. As already stated thirty-three lines of this series of hydrogen have been seen in the spectra of stellar nebulae.

There is another series of hydrogen lines confined to the ultraviolet region. This is termed the *Lyman series*. On the basis of the Bohr model the one-quantum orbit is the final one. (See Fig. 16.) Electrons in jumping from outer orbits to it emit these lines. A series of hydrogen lines in the infra-red, known as the *Paschen series,* is accounted for by assuming the three-quantum orbit to be the final one to which electrons from outer orbits jump in producing the infra-red series.

Bohr's theory scored another triumph when it revealed the fact that certain spectral lines which had been attributed to hydrogen were actually a helium series. This was afterward experimentally proved. However, this triumph was not

achieved until he modified his model so as to eliminate the differences between his calculated frequencies and those determined by the spectroscope. His modification consisted

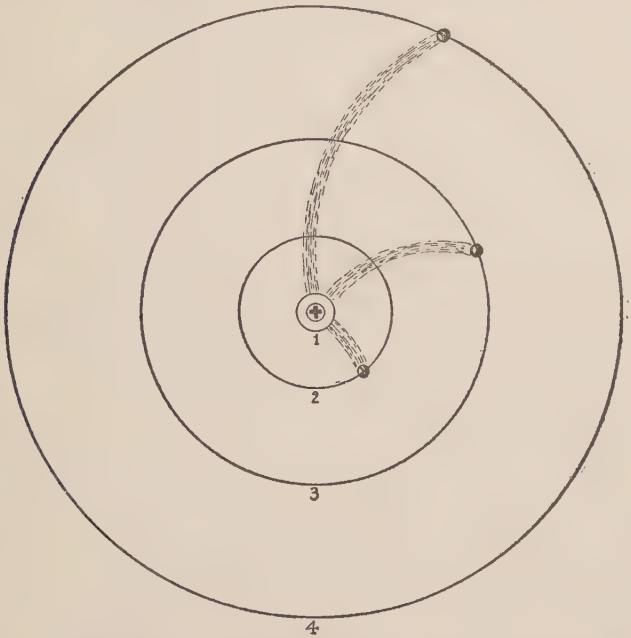


FIG. 16. The Lyman Series of hydrogen are assumed to be produced in a manner similiar to that of the Balmer Series, excepting that the one-quantum orbit is the final one. That is, radiations of these frequencies are produced by electrons falling from the outer rings to the one-quantum ring.

merely of recognizing the fact that, according to mechanics, the electron does not revolve around a point which is the center of the nucleus, but both the electron and nucleus revolve around a point which is at their common center of gravity. This actual axis is nearly at the center of the nucleus, but not quite. It will be recalled that the Moon revolves around a point not at the center of the Earth, but around one at a

distance from this center. This point is such that the product of the mass and its distance from this center of revolution is the same for the two bodies. In other words, this center of revolution lies on a line connecting the two masses and is at a distance from each mass inversely proportional to its mass. It is close to the point at which the two masses would balance if connected by a rigid rod which itself had no mass. The mass of the helium atom is about 7400 times that of the electron so it is seen that the correction is not large. However, by including this refinement in his model, he was able to compute the frequencies of the helium lines so that they agreed with those actually measured by experiment. Bohr computed from his mathematical relations the mass of the electron and the result agreed very well with experimental determinations of it. Thus it is seen that many triumphs have been scored by the Bohr theory of atomic structure.

Structure of Spectral Lines

If electrons revolving rapidly are the cause of radiations of certain characteristic frequencies which the spectroscope records as spectral lines, it seems reasonable to expect that a powerful magnetic field should alter the appearance of the lines. A moving electron has the characteristic of an electric current and it is well known that a magnetic field tends to move the conductor carrying the current when the field is at right angles to the direction of the current. If the orbit of an electron is circular, a magnetic field should tend to enlarge or to shrink it, depending on the direction of rotation with respect to the direction of the magnetic field. Certainly the frequency of revolution should be altered and, therefore, the frequency of the emitted light should change.

Zeeman in 1896 discovered that when atoms emitting light

of characteristic frequencies were subjected to a strong magnetic field, single spectral lines became triplets and even more complex. The middle line of a triplet was of the original frequency, but on each side of it was a line, the two being of higher and lower frequencies, respectively, than the middle or original line. Those electrons whose orbits are parallel to the applied magnetic field will be unaffected, thus accounting for the unchanged line. The other orbits will be equally divided (owing to the great number) into two classes. One class will have electrons rotating in one direction, the other class in the other. In one case the electron will be drawn into a slightly smaller orbit and, rotating faster, will emit a higher frequency. In the other case the electron will be pushed outward with a resultant larger orbit and lower frequency. This follows from ordinary mechanics and magnetics. This effect of a magnetic field on spectral lines is known as the *Zeeman effect* after the discoverer.

When atoms which are emitting light are subjected to a powerful electrostatic field between two plates connected to a high voltage, a similar effect is noticed. This is termed the *Stark effect.*

Sommerfeld, in closely observing certain hydrogen and helium lines, noticed that they are complex, that is, they have a structure similar to those observed in the Zeeman and Stark effects. Bohr had called attention to the possibility that the principle of relativity — the variation of mass of an electron with its velocity — might have to be taken into account in the atom. Sommerfeld applied this relativity correction to the electrons which move with a velocity of one or two per cent of that of light (Chapter VII). He also substituted elliptical orbits for the circular ones of the Bohr model. The combined result was a satisfactory accounting for the structure of these lines. Many other interesting developments followed this modi-

fication, but a discussion of them would lead us far afield. By introducing the elliptical orbits the theory of the Bohr atom becomes much more complicated, because an ellipse is expressed by two magnitudes (two axes) whereas a circle is expressed by a single one (the radius).

The new viewpoint of the Rutherford-Bohr-Summerfeld atomic model gives to spectroscopy a much greater importance in theoretical physics. By measuring the frequencies of spectral lines and combining these with the value of the electric charge, various important constants have been determined. Even Planck's constant h may be determined from spectroscopic measurements.

Sommerfeld's Modification

Sommerfeld introduced into the Bohr theory the relativity principle; that is, that the mass of the rotating electron changes during its orbital motion. Also as Kepler altered the Copernican circular orbits of the planets, so he substituted elliptical orbits for Bohr's circular ones in the atom. The velocities of the electrons are not negligibly small with respect to that of light, so their mass must be somewhat greater than 8.9×10^{-28} gram which is its accepted stationary or low-velocity value. Thus he had to abandon classical mechanics which Bohr could apply to his uniformly revolving electrons in circular orbits. It is obvious that the single-quantum number for each stable orbit had to be replaced by two-quantum numbers for each possible orbit. It should not be difficult to see that an electron jumping from one orbit to the final one can leave one of the two-quantum numbers of an elliptical orbit and arrive at one of the two-quantum numbers at the final elliptical orbit. Another electron can do differently; therefore, a spectral line may actually be complex. The two-

quantum numbers for any given elliptical orbit differ only slightly, but just enough to account for slightly different spectral lines. The relativity effect is small so the difference in the two spectral lines due to the transition of electrons from the same orbit to the final one is small. Therefore, the components of any hydrogen line are very close together, but nevertheless the lines are not necessarily single. The two frequencies corresponding to the components of a doublet differ by a constant for all the doublets. Incidentally, the frequencies are so nearly alike that instruments of the greatest resolving power are required to separate them. The theoretical difference called for by Sommerfeld's modification agrees with the observed values.

Sommerfeld's theory also explains such complex structures as that of the red hydrogen line which consists of five lines in two groups of two and three lines respectively. The mean distance between these two groups according to the theory is almost identical with that determined by actual measurement. The theory has also successfully accounted for the *Fowler series* in the helium spectrum. The Sommerfeld theory has made it possible to determine with great accuracy from spectroscopic measurements the value of Planck's constant and the charge and mass of the electron. Thus there seems to be much proof of the existence of stable orbits in which the revolving electrons do not emit light and also of the change in mass of the electron during its movements within the atom.

It will be recalled that Einstein and Haas detected a rotational mechanical effect produced when an iron bar is magnetized. Assuming that the magnetism of iron is due to revolving electrons, these results, as pointed out by them, indicate that electrons can revolve without emitting radiant energy. The iron bar was at room temperature and certainly was not

emitting radiant energy characteristic of "excited" atoms. This supports the possibility of existence of the stable orbits or quantum orbits assumed by Bohr in which revolving electrons do not emit light.

Elements of Higher Atomic Number

The hydrogen spectrum is so well accounted for that it appears that the structure of its atom is approximately known. A helium series is also accounted for. In fact, in both cases the details even of the fine structure of the lines are accounted for with surprising precision. Lande devised a model of a helium atom in which two electrons revolve in two different orbits around a nucleus of two protons, the orbits being either at an angle with each other or in the same plane. The electron farthest from the nucleus emits light. It moves in the field of the inner electron so that a complex situation arises. A beginning has been made, but nothing more. As the atom becomes more complex the difficulties of mathematical treatment increase enormously.

Results of the Bohr Theory and Its Modifications

Although there are many unsettled points pertaining to the Bohr theory and its modifications, it has achieved remarkable results. The chief ones are as follows:

It has accounted for the Balmer-series and other known series of the hydrogen spectrum.

It has evaluated the Rydberg constant and shown its universal nature.

It has determined the normal diameter of the hydrogen atom to be (half the value of the hydrogen molecule) 1.1×10^{-8} centimeters.

It has explained why normal hydrogen does not exhibit all the lines of the Balmer-series.

It has successfully predicted the lines observed in stellar spectra of hydrogen.

It predicted spectral lines that were afterward discovered.

It has accounted for the *Stark effect* or the effect of an electrostatic field in splitting up spectral lines in the cases of hydrogen and helium.

It has explained the fine structure of hydrogen lines.

It has explained the *Zeeman effect* partially.

It has accounted for the *Fowler series* of helium.

Other Models

Although the models already discussed have received the most attention, others are well worth discussing. However, it is not the purpose of this book to enter far into the unsettled fields. The Bohr model was discussed along with its modifications not only to give the reader a glimpse of a field of great scientific activity, but also because it afforded a good opportunity to discuss spectra of elements.

Atomic models have been devised in which the electrons are relatively fixed. The chemist finds this hypothesis helpful in explaining valence and various phenomena such as vaporization, temperature, solution, etc. The Lewis-Langmuir model seems to be the most developed in this direction. In this model the electrons in atoms occupy definite positions distributed through a series of concentric, or nearly concentric spherical shells whose radii form an arithmetical series, 1, 2, 3, 4, etc. Each shell is divided into cells of equal area. These cells are assumed to exist independent of the electrons. The properties of the atoms are determined chiefly by the number and arrangement of electrons in the outer shell and by the ease with which

the atoms can give up or take up electrons. Electrons can be shared or held in common by two atoms. They can exist in a free state or as bonds between atoms. The positive nuclei are associated with the electrons. It is claimed that this theory explains the periodic, magnetic, physical, and chemical properties of elements. This is an extremely interesting theory particularly from the chemical viewpoint, but an extended discussion of it is not within the scope of this book.

Chapter XIV

THE FATEFUL UNKNOWN

A comparison of our knowledge of the physical world with that of primitive men or, even with that of the highest civilization a few centuries ago, shows that science has made very great progress. We seem to be at the doorway which leads to a knowledge of the very fundamentals of Nature, but when we pass that portal will we not find another? From our past experience is it not logical to ask, "Will we ever reach the beginning of things?" Not long ago the atom seemed to be the fundamental "brick" of matter; now we know that it has a structure. The electrons and protons of which atoms appear to consist, we say are *electricity*. What is electricity? This we do not know, but we are learning more and more of its manifestations. Will this knowledge ever lead us finally to an ultimate complete understanding of matter? We are encouraged to believe that we will eventually know all that human minds can ever know and comprehend in this direction. But that may leave us far from the complete solution of the universe. We cannot know all until we know what mind is, so that we may allow for its limitations.

Such reasoning leads us far afield into the metaphysical world. Enough remains to be solved in the physical world before science finds itself at the frontier of the metaphysical. By incessant attack we have reached a point where it appears that matter is electrical in constitution and where matter is closely akin to, or even, energy itself. Recent developments have been nothing short of marvelous when we compare the

ideas prevalent now with those of only a quarter of a century ago. Matter and energy are the chief interests not only of science, but also of nations and of individuals. From a purely selfish human viewpoint, the transmutation of elements and the utilization of the enormous energy which we know is stored in atoms are the more interesting phases confronting us. Let us review some of the possibilities.

Transmutation of Elements

The adoption of gold as a standard of value is based upon the rarity of this element and carries with it the presumption that gold will not be discovered in sufficiently great quantities to disrupt the economics of human intercourse. But suppose the Mother Lode of fiction should be discovered. Suppose someone came back from beyond the frontiers of civilization with a tale of mountains of solid gold. If this were found to be true, a great upheaval in economic life would result provided the gold could be obtained at a cost negligible to its present value. Fortunately, the cost of obtaining gold from any of the deposits heretofore discovered has not been negligible and the quantities discovered have not been disturbingly great.

Before 1896 when Becquerel discovered radioactivity, a suggestion that elements emitted electrical particles and radiant energy, thereby transmuting themselves into other elements, would have been given little attention beyond pronouncing it a wild dream of the imagination. Now this is a reality which has given us much knowledge of the mechanism of the atom and of the relations of elements to each other. If we had to purchase the energy at current rates necessary to build up an atom of gold, an ounce of "manufactured" gold would be many times more precious than natural gold. But if we could take the elements of higher atomic weight

and cause them to emit alpha particles spontaneously without much effort on our part, the outlook would be more promising. Soddy calls attention to several recipes for the modern alchemist. For example, if actinium D or thorium D had expelled an alpha particle (see Chap. X) instead of a beta particle, the product would have been gold instead of lead. It will be recalled that gold is found in the periodic table of elements two spaces ahead of thallium. If a means could be found of causing a thallium atom to give up an alpha particle, a gold atom would be the result. Similarly, atoms of gold would be produced if an atom of lead gave up one alpha particle and one beta particle or if an atom of bismuth gave up two alpha particles. In these cases the result would be an isotope of gold — differing from natural gold only in atomic weight, — but inasmuch as its properties would be identical with those of natural gold the new elements would be gold as far as an assayist was concerned.

Chemical changes in which atoms of elements alter their alliances are processes which apparently involve only the outer portions of the atoms. Radioactivity involves a deeper disturbance. Similarly, the artificial transmutation of elements must involve the nucleus of the atom. If this can be altered at will in a practical manner, mankind will find himself realizing the dream of alchemists of old and of dreamers of all centuries. Rutherford has been able to knock out portions of the nuclei of atoms. By no means is science at the end of its highway. In the stellar crucibles elements are found under conditions of temperature and pressure that have not been produced by Man. The astrophysicist has much before him that he has not fathomed. What he will reveal can only be conjectured, but we can safely expect much. In the heavens are found glowing nebulae, extremely tenuous, where atoms are glowing in the relatively great freedom of very low pres-

sures. On the other hand great pressures exist and these may be producing changes in elements of which we know nothing. It is estimated that the pressure at the center of the Earth is several thousand tons per square inch. If two stars should collide it has been computed that the pressure at their centers would be many million tons per square inch. What undreamed of alchemy could take place under such inconceivable pressure at a high temperature.

Radioactivity is a process which we now know has been going on for countless centuries. Those products which are short-lived are naturally not found in abundance. The long-lived products are the most plentiful. Their abundance is gained at the expense of the less stable ones. Uranium is present in the Earth in relatively large quantities. The relative abundance of two elements is not solely dependent upon their stability or length of life as viewed from our knowledge of radioactivity. They may belong to different "series" of disintegration. Who can say that gold, silver, iron, lead, and other elements are not disintegrating? Perhaps they are, but so slowly that changes have not been detected. Matter when viewed superficially does not appear to be undergoing any elemental change. Its elements seem to be constant in proportion. The discovery of radioactivity altered our attitude in this respect and we cannot be expected not to conjecture as to the possibility of radioactivity being a universal process varying enormously for different elements. Is it unreasonable to suppose that apparently stable elements are radioactive but at a very slow rate of disintegration? If this is unreasonable, at least, we can expect much in the great cosmic crucibles where conditions of temperature and pressure are extraordinary from the viewpoint of the "artificial" world of human beings. Evolution has become almost a universal doctrine. May it not be a process applicable to atoms and stars?

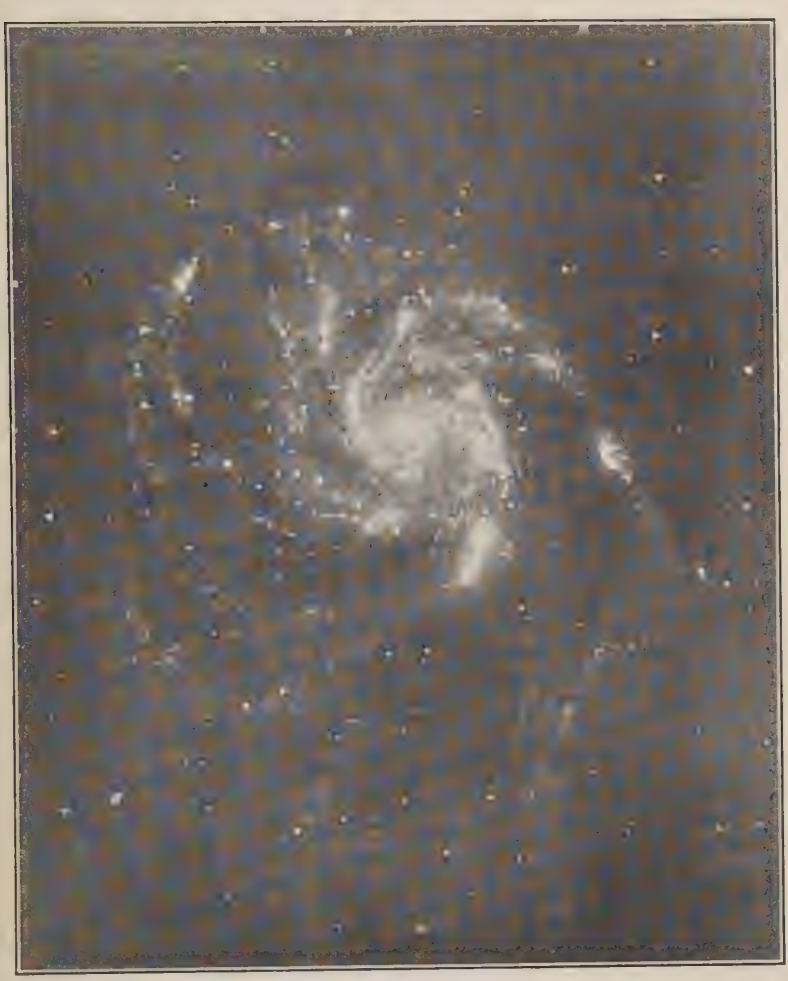


FIG. 17. A Stellar Nebula.

Energy

In our complex economic life, energy is a very important matter. We have developed water-power. Nature carries water for us to the heights and we are utilizing some of the energy of the mass of water as it seeks the oceans under the influence of the Earth's attraction. In coal deposits we find energy stored ages ago. The sun and the soil combined to furnish the energy which was stored up during the growth of the vegetable matter in those by-gone ages which is supposed to be the origin of coal. In burning this coal, carbon and oxygen unite. Much energy is liberated during this reaction which heats things for us.

We burn the coal under a steam boiler and impart some of this energy to the molecules of water. They are greatly agitated and steam results. The high pressure is due to the kinetic energy of the molecules which has been increased by some of the energy accompanying the chemical reaction of the carbon and oxygen. The steam is led into a cylinder where its high pressure pushes a piston. The kinetic energy of the molecules of water-vapor decreases. Some of this energy is transformed to mechanical energy and some of it is lost by radiation from the parts of the engine which are hotter than the surroundings. Other losses of this character take place from the boiler and piping. Some of the mechanical energy of the engine is absorbed by friction before the final amount reaches the place where we want work done. The steam after it has done its work still has much kinetic energy. The efficiency of the process is low not only because of wastage by friction and by radiation, but because all the kinetic energy of the water molecules is not released. This would happen only when the final stage of the process was at absolute zero.

In the engines of our automobiles chemical reactions are

going on and losses of energy are taking place. The efforts of the engineer are directed toward reducing the losses. He knows that at best he can achieve only a low efficiency. He is dealing with the kinetic energy of molecules and he can only utilize at most the difference between the kinetic energy of the gas or vapor admitted to the cylinders and that remaining in the exhausted gas or vapor. Throughout these processes we are dealing with molecular energy which, in the light of modern knowledge, is a sort of residual energy left over from the atom. We have had glimpses of atomic energy and have seen that it is enormous compared with the energy of chemical reactions which, before the discovery of radioactivity, was the only energy considered in dealing with elements. This is encouraging not only because we see supplies of coal, oil and gas diminishing, but on account of the enormous supply which is awaiting us. Instead of viewing a continual decrease in the supply of chemical energy we now view this as a mere residual of great atomic supplies whose existence was unsuspected until thirty years ago. When we have learned to tap this storehouse we will know how to transmute elements, but then the energy will be more valuable than the manufactured gold, platinum, and silver.

By uniting hydrogen and oxygen to form water (burning the hydrogen) a certain amount of energy is obtained with the formation of each gram of water. According to Crowther, when a gram of radium emanation (atomic weight = 222) completely disintegrates through its series of products to a stable element with an atomic weight of 210, the total energy of this change is about 600,000 times greater than the energy produced by the chemical combination of an equivalent weight of hydrogen and oxygen. It will be noted that the atomic weight of the final product is still 210. What a tremendous store of atomic energy must still remain in the gram of the

final product. We could multiply many fold the comparison between atomic energy and so-called chemical energy if it seemed necessary to do so to be convincing. But the tremendous supply of atomic energy is so overwhelmingly greater than that which we have been used to in chemical reactions that one example is sufficient to illustrate the difference.

The energy resulting from radioactive changes is generally measured in terms of calories, a calorie being the amount of heat necessary to raise a gram of water one degree Centigrade. The kinetic energy of the alpha and beta particles is dependent upon their masses and velocities. The velocities of alpha particles emitted from radioactive elements are in the neighborhood of 10,000 to 15,000 miles per second. Those of the beta particles vary from one third to nearly the velocity of light. They impart their kinetic energy to the molecules of the substance whose average amplitude of vibration is increased, with the result that a higher temperature is manifested by the substance.

Energy of Celestial Bodies

Let us first take a glimpse of the sun. It is an example of enormous activity. Its mean temperature as determined by the color of its light is over 10,000 degrees Fahrenheit. Great flames extend from its surface sometimes several hundred thousand miles. The sunspots covering thousands of square miles contain powerful magnetic fields possibly produced by the moving electric charges in the great swirls of glowing vapor. The beautiful aurora borealis is probably due to electric charges, such as alpha and beta particles shot out from the Sun and ionizing the upper atmosphere of our Earth after traveling over ninety million miles. These facts are mentioned to illustrate the enormous scale of celestial processes.

The age of the Sun and the source of its energy have been considered from many viewpoints. Laplace believed that our Sun originally extended as a tenuous glowing vapor beyond the orbit of Neptune. It rotated on an axis and gradually contracted as it cooled. During the contraction it left behind certain portions which gradually rotated themselves into spherical shapes. These are the planets of the solar system. It is still at such a high temperature that it is in a gaseous state, but according to Laplace, it is shrinking and cooling slowly toward a final solid cold state. The correctness of this hypothesis is now very much in doubt. Incidentally, the Sun is so large that if the Earth were at its center the Moon could revolve around it and still remain well below the surface of the Sun. The great flames extend from the Sun sometimes a greater distance than that of the Moon from the Earth.

Stars are now considered in their early stage to be of a very light-density gas at a comparatively low temperature, although, of course, self-luminous. They contract gradually as they lose heat by radiation, but the heat produced by contraction is supposed to be greater than that lost by radiation. Therefore, they gradually attain a higher temperature. According to this hypothesis they do not start at their highest temperature, but attain it during their evolution. This procedure continues as long as the star remains tenuous enough to obey the laws of a *perfect gas*. After it has contracted so much that its density is such that it is no longer a perfect gas, the temperature gradually decreases. All this time the temperature is so great that no chemical compounds exist. In fact, the elements are all gaseous and in the case of the hottest stars only the simpler elements, such as hydrogen, helium and nitrogen are found. In fact, there is a group known as *helium stars* because of the prominence of this element in their atmospheres. Still it is a relatively rare gas on Earth. Is it pos-

sible that in the course of evolution of the Earth it has largely been utilized for constructing the higher elements? It will be recalled that helium was discovered in the Sun by Lockyer, twenty-eight years before Ramsay found it in the Earth's atmosphere. An element *nebulium* has been found in gaseous nebulae, but is still undiscovered on Earth.

According to Eddington, energy of the Sun and of other stars cannot be adequately accounted for on the old contraction hypothesis. According to the old view the initial stage of evolution of a star to its highest temperature would occupy less than one thousand centuries. Modern knowledge indicates that the actual duration of this period is many times greater. Some additional source of energy seems to be necessary to account for solar and stellar energy. The modern view of matter considers the possibility of all elements being constructed of hydrogen atoms; that is, of hydrogen nuclei and electrons. Eddington computes that if five per cent of a star's mass consists originally of hydrogen atoms, the total energy of the star would be accounted for by the gradual evolution of these atoms into elements of higher atomic weight.

The extraordinary conditions of pressure and temperature may bring about changes in elements of which we know nothing, owing to a lack of experimental data obtained under these conditions. According to Cook, the pressure at the center of the Earth is a few thousand tons per square inch, while that at the centers of two colliding stars would be a billion tons per square inch. If a projectile from the largest cannon ever built were fired into steel, the greatest pressure produced would be only a few thousand tons per square inch. Thus it is seen that the stellar laboratories may give us much of the information desired which we are unable to obtain in our own laboratories. Pressures of twenty-five tons per square inch and temperatures of 20,000 degrees Centigrade have

been produced in the laboratory, but these have so far been attained only for a fraction of a second.

Radioactivity and the construction of higher elements from hydrogen atoms may be playing prominent parts in the manufacture of stellar energy. Apparently the length of time that is necessary for the Earth to cool from its original state to the present one is not long enough to suit the geologist. He needed hundreds of millions of years. The estimate of the period that the Earth has been sufficiently cool to account for geological formations can be greatly extended if we consider that radioactive elements have been supplying energy which retards the cooling rate. With the average life of uranium about eight billion years we have a process which is long enough for such a purpose even without considering any other radioactive process. With uranium evolving a million times more energy than the chemical reaction of an equal weight of coal and oxygen, we need have no fear of the inadequacy of the radioactive process to account for much energy.

John Joly, among others, has made some interesting computations starting with an assumption of a proportion of radium, throughout the Earth, considerably less than that which exists in surface layers. He assumed two parts in every thousand billion parts. In one hundred million years this radium could account for a temperature of the central region of the Earth of over 3000 degrees Fahrenheit. The surface layers of the Earth have very low heat conductivity and, therefore, this heat does not escape rapidly. On this basis the Earth may actually be getting *hotter* instead of cooling. Furthermore, this suggests that the Earth may actually alternate from a hot stage to a cool one, time and again. During the incandescent age the stored "heat" would be radiated very much more rapidly than supplied by the radium. According to this view, the Sun is losing heat much more rapidly than

it is being generated at present and this loss is being supplied from the energy stored at the center for ages. There is no indication of sufficient amounts of uranium in the Sun to supply energy at the present rate of loss by radiation.

The End?

Recent knowledge offers new avenues of thought and speculation. Before we knew what we now know of the evolution of elements, the old scheme of the universe had to be built on the principle of a beginning and a cold lifeless end. The universe was wound up (supplied with potential energy) and set going. This was always an inadequate view from a philosophic standpoint. Surely Nature could devise a continuous process which could endure longer. It seems hardly worth while to have this one short span reckoned cosmologically. Of course, we are looking at this from a human viewpoint. How inadequate our perception must be! We do not know what *Mind* is even though it is the vital thing which makes us want to know about the universe. Certainly there is a place for Mind in this great scheme of the universe. Each entity of Mind, it seems reasonable to believe, endures longer than that tick of the cosmological clock which registers generations of human lives. But we are drifting from the physical universe which is natural, because after all, when we fathom its mysterious depths we must encounter mind not as a human tool, but as an imperishable *element* in the unseen cosmos.

In a previous paragraph we saw the possibility of a cosmic cycle. In the stellar crucibles higher elements are being constructed of hydrogen. Great energy is generated at the same time that potential energy is being stored in the atoms. When this process is over and the body cools sufficiently the incandescent age is followed by a geological age. Finally, life

may appear which is suitable to the conditions. In this Great Evolution the evolution of life is just a branch. It goes on until Man arises by degrees out of the ages of plant and animal development. The energy stored in the atoms in the cosmic crucible eons ago is gradually being dissipated by spontaneous disintegration. Heat energy may accumulate in the center of the Earth, which counteracts more or less the loss by radiation. Possibly it accumulates faster than it is lost as the surface layers of the Earth become less conducting through geological formation. If so, a cycle of increasing temperature begins which may continue until the Earth again becomes incandescent and all geological strata and life are destroyed. It now loses heat rapidly by radiation which is proportional to the fourth power of the absolute temperature. Possibly in this cosmic crucible energy is again stored in atoms to be dissipated slowly in a repetition of the cycle. Even without this, the cycle could conceivably repeat many times before the atomic energy is all dissipated.

How about the continual loss of energy radiated outward in space? But is there an absolute loss? Is it not conceivable that energy cannot be lost from the universe. Radiant energy is subject to the new law of gravitation. A beam of light is bent toward each celestial body that it passes. Can it ever get completely away from the universe? Is it not possible to conceive that it describes an elliptical path, highly eccentric though it may be, which returns eventually to strike stellar bodies, thereby not being *lost* irrevocably. This may tax our imagination, but not as much as conceiving an irrevocable loss. Energy and mass are interchangeable according to the latest views. Space may be boundless, but still limited, because it is *curved* space. Radiant energy emitted by stellar bodies may travel with its great velocity always *within the universe* eventually to be transformed into kinetic energy again as it strikes matter.

These possibilities could be elaborated upon at considerable length, but obviously could not be proved. They are reasonable even in their unreasonableness, because they are conceivable. The everlasting cyclic process is more satisfying from a philosophic viewpoint; less inconceivable than a process which allows for losses of energy in a great unknown; more reasonable from the point of view of orderliness and method in Nature. Many mysteries exist. What controls the steady rate of disintegration of elements? In our ignorance, it is natural to picture a guiding spirit. Heretofore, in the history of Man, whenever knowledge replaced ignorance, a necessity for a guiding spirit disappeared. However, as we approach the ultimate, such as the nature of electricity — which apparently has the property of holding elements together and of giving different properties to them — it seems that eventually Mind in some way must enter. Whether it does or not cannot be settled here. However, in closing it may be said that one cannot intimately view the mechanism of the universe or approach close to the ultimate without at least feeling the urge and even need for belief in God. Not the emotional God of primitive beings, not the recording God of our creeds of narrow outlook, but the omnipresent Mind that is at the bottom of things. Perhaps of this Mind, that part of us which does not "to dust returneth" — the human mind — is an *atom* which also is in the process of evolution.

"Flower in the crannied wall,
I pluck you out of the crannies,
I hold you here, root and all, in my hand,
Little flower — but if I could understand
What you are, root and all, and all in all,
I should know what God and Man is."

Tennyson

Chapter XV

THE GROWTH OF KNOWLEDGE

Through the knowledge which Man has gained of the foundations of the universe, he is able to span great distances in space and in time. He knows much concerning the distant stars. He can make many predictions with certainty for long periods into the future. He knows a great deal concerning what happened long ago. But these magnitudes dwarf into significance when we apply *our* distance-scale to the universe and *our* time-scale to its evolution. It is then that we realize that the universe is a " going concern " for which time is certainly infinite and space is probably something akin to boundless. The entire span of life on this Earth from the first primitive cell until now is only a cosmological second on the clock of the universe. In another tick of that clock this planet may be a cold lifeless one. How the foundations of the universe were laid is a mystery, but it is possible that our knowledge may eventually be sufficient to answer. We are encouraged by our successes of the past in learning something of the foundations of the universe even though we are only an insignificant part. We are handicapped by inadequate senses, but these have achieved much, notwithstanding the incomplete picture of the physical world which they provide.

Even though we could sit in a grandstand and watch the parade of the evolution of the human race pass by, we could not point out the first *human being*. Man did not begin; he modulated. Recorded history is only about 6000 years old and much of this is fragmentary. Some kind of primitive men existed per-

haps a half million years ago. The slow evolution of Man has a parallel in the gradual increase in knowledge since recorded history began. Likewise the growth of knowledge has a parallel in the learning of a child. Knowledge is the amassed thought and experience of countless minds. The child is born with whatever heredity bequeaths it. This inheritance is perhaps more than a capacity for learning. If we watch a child learning to coördinate sight and touch as it passes its hand over an object, we see a picture of early Man feeling his way in the world about him.

As we look backward we may be inclined to be amused at the ignorance of high civilizations only a thousand years ago. But when we think of early Man in terms of the present-day babe we are inclined to soften our view. Each generation inherits all that has been acquired before. Each babe on the average is born with a greater capacity than its predecessors. With this greater capacity is also a greater inheritance of accumulated knowledge and with all this is a civilization which exemplifies on every hand the fruits of knowledge. Is it any wonder that the growth of knowledge is ever gaining momentum? It should continue to accelerate. The achievements of each decade on the average should be multiplied many fold in the next one, and so on. We have no right to be more proud of the accomplishments of our generation than those of the past generation were of theirs. If we base our theories on sound experiment now, it is because we have learned to do so.

It seems profitable to devote some pages to a view of the growth of knowledge pertaining to the foundations of the universe. In the preceding chapters the reader has made this trip, but the pauses have been so long at some of the milestones that he may not have gained a true picture of the growth in regard to time. Furthermore, we have not visited the milestones in succession because it seemed best to present the

subject systematically rather than chronologically. We started with the more obvious phases of the physical world. After learning something of matter and its motion we reached outward and applied this knowledge to the world which we could see with the telescope. Then, equipped with greater knowledge we gave our attention to the mysteries which our eyes with their optical aids could not observe. Chronologically the picture is somewhat altered and, therefore, it seems worth while to pass along the highway of knowledge as it extended from year to year. In doing this we will concern ourselves only with those men whose work contributed directly to the unravelling of the mysteries of the foundations of the universe. It is a matter of judgment where to begin so it seems best to leave out of consideration much of the early philosophy.

The Hindus, Arabs, and others contributed something to early mathematics and astronomy, but this early work is of importance chiefly as a setting for what followed. Therefore, let us begin with the early Greeks who did so much to establish science and interest in it.

The Grecian Contributions

Thales (*640–546* B.C.) was born in Ionia, a Grecian colony, but made visits to Egypt as a merchant. He was also an engineer and while in Egypt he learned something of astronomy and geometry. He brought this knowledge back to his country and taught his countrymen. He propounded some original theorems in geometry. With the borrowed knowledge and his own contributions, Thales is responsible for the beginning of some great developments in geometry. The Greeks were particularly inclined toward logic. Although his geometry was sound, he thought the Earth was a circular disk

floating on water which was the fundamental element. On the other hand, he taught his countrymen some sound facts of astronomy, such as, the Moon is illuminated by sunlight.

Anaximander (*611–545 B.C.*) was a pupil of Thales. He studied shadows due to the Sun and developed the sun-dial. He followed the pathway of his teacher in most things, but believed that the Earth was balanced in the center of the world and that it was shaped like a column. A circle of fire surrounded the Earth, but was separated from it by the air. In the atmosphere there were holes through which the stars could be seen.

Anaximenes (*588–524 B.C.*) was also directly in line with the two preceding Ionian Greeks. He went on with their teachings of geometry. He believed that air was the fundamental element and that the stars are fixed. The Sun's heat was attributed to its motion.

Pythagoras (*582–500 B.C.*) founded his well-known school which developed arithmetic, geometry, astronomy and physical science. He studied the emission of sounds by vibrating strings. He believed the universe to consist of four elements —air, fire, earth and water. He had weird ideas of the motions of stellar bodies, but his teachings that the planets, including the Sun and Moon, revolved around a "central fire" paved the way for the Copernican theory 2000 years later. Doubtless much that was attributed to him was originated by members of his secret society which were pledged to reveal their ideas and discoveries only to him.

Anaxagoras (*500–428 B.C.*) was a wealthy Greek who developed a liking for science. Like his predecessors he devoted himself to mathematics with success. He established the idea that all matter consisted of elementary substances, thereby being credited with the origination of atomism. For his teachings he was convicted of impiety and was exiled.

Democritus (*460–370 B.C.*) further developed the idea of atomism. He believed that nothing happened by chance and that the only existing things were atoms and empty space. Substances he believed depended upon the size, number, and arrangement of their varieties of atoms. He propounded the theory that there was a cause for every occurrence. Even though these ideas were not based on experimental evidence, they were valuable in directing thought along the proper channels.

Plato (*427–347 B.C.*) is famous as a philosopher. This Grecian pupil of Socrates philosophized much upon the Earth, the universe, and the human mind. He encouraged mathematics and did much to unify it. He developed some famous axioms. However, on the whole, science was a secondary matter in his teachings. He contributed little toward the development of astronomy excepting by preaching the doctrines of his predecessors. He accepted the idea of uniform circular motion of the planets, but he believed that the Earth was the center of the universe.

Aristotle (*384–322 B.C.*), a tutor of Alexander the Great, did much for science. He made some contributions to mathematics, mechanics, physics and astronomy. He was master of the principle of the lever and knew how to compute the point at which unequal weights on the ends of a bar would balance. He erroneously believed that the speeds of falling bodies were proportional to their weights. He was so influential that nearly 2000 years later Galileo had difficulty in convincing his followers otherwise by actual experiments. He believed that the Earth was spherical and that its circumference was 39,000 miles. (It is about 25,000 miles.) Who made this estimate is unknown. He adhered to the idea that the four fundamental elements were earth, fire, water and air. Of these the Earth was at the center of the universe, water

was next, and fire and air were in the space around the other two. In this space shooting stars, comets, and the Milky Way consisted of flames. The apparent fixity of the stars seemed to him to prove that the Earth did not move in an orbit.

Euclid (*330–275 B.C.*). Physical science could not develop without mathematics and, therefore, the work of Euclid is perhaps unexcelled from the viewpoint of influence on scientific development. Little is known of him personally, but his works on mathematics have formed the foundation for presenting elementary geometry for over 2000 years. We recall the definite logical form of his propositions. His treatise holds the record for duration of influence. He was connected with the university of Greek science — the Museum at Alexandria, Egypt.

Archimedes (*287–212 B.C.*) was a mathematician, physicist, and engineer and may be considered one of the greatest men in scientific history. He not only contributed to mathematics, but laid the foundation of mechanics. He added to the development of geometry and almost invented infinitesimal calculus. He was interested in many phases of science and performed many experiments. He discovered the fact that a body in water lost weight equivalent to the weight of the water displaced. He developed various mechanical devices, some of which were used by the armies of Syracuse, where he was born and lived. When Syracuse fell before the assaults of the Romans in 212 B.C. he was killed by a Roman soldier.

Hipparchus (*146–126 B.C.*) was the greatest astronomer of early centuries. He lived at Rhodes where he made many astronomical observations, many of which were quite accurate considering the facilities he had. He found that the Sun's distance from the Earth varied throughout the year. He discovered the precession of the equinoxes by comparing the positions of the stars with those recorded more than a century

earlier. He correctly concluded that the Earth's axis slowly rotates so that the poles describe a circle in the course of many centuries. He still believed that the planets, Sun, and Moon revolved around the Earth. He catalogued a thousand stars and made many other systematic astronomical measurements. Perhaps his greatest contribution was the invention of trigonometry.

Ptolemy during the second century A.D. took up the work of Hipparchus which had not been added to for 250 years. He devised better astronomical instruments, but no means for accurate time-telling had been devised. He still used the method of flowing water for measuring time. He wrote treatises which embodied all that was known of astronomy. He believed that the Earth was a sphere, but still adhered to the idea of its being located at the center of the universe. His treatises were the accepted standard for 1000 years. During these ten centuries the science of astronomy stood still because men accepted the established theories in the face of facts which contradicted them. Ptolemy made some original contributions to mathematics and prepared a geography of the known portions of the Earth in which the latitude and longitude for many places were presented. He also determined the maximum duration of the day for many of these places.

The Dark Age

Much of the Greek domain was destined to become Roman. The steady progress of science was to cease under the autocratic Roman rule and the hostility of the Christian church. There were many defects in the Greeks' science, but all combined are insignificant compared with the great defect of the ruling power of the next eight or ten centuries which inhibited development of this kind of knowledge. The coming

centuries are the "dark ages" and, as we pass along them in our hurried trip along the pathway of knowledge, we cannot avoid noting to the everlasting discredit of Roman and Church rule the lack of interest in science. Perhaps we should be generous enough, as we hurry along these dark centuries of science, to imagine that we hear the gifted Roman orators reciting the works of gifted writers such as Cicero and Virgil. But can we at the same time deafen our ears to the clash of arms commanded by the military geniuses of these centuries?

Capello in the fifth century wrote on mathematics and astronomy and *Boethius* (*480–524*) also introduced Greek science to medieval civilization. Justinian closed the schools of Athens in 530. Charlemagne in 787 established many schools from which the subtle Scholasticism of the Middle Ages arose.

The Renaissance

In the thirteenth century the renaissance of science began. As a result of this awakening many universities arose. The algebra and arithmetic of the Hindus and Arabs and the Greek works in mathematics and physical science were translated into Latin. This renewed interest spread from Italy through the Continent and into England.

Roger Bacon (*1214–1294*) after his education in Paris, became a Franciscan monk and a brilliant scientist. At the invitation of Pope Clement IV he prepared treatises of the various sciences, but he was chiefly interested in mathematics and physical sciences. He reformed the calendar so as to eliminate the error of one day in each 130 years. He contributed much to optics and predicted that, owing to the sphericity of the Earth, the ocean "between the east coast of Asia and Europe" (not knowing of the western continents) was not extensive. This statement was one that inspired

Columbus two centuries later. His works were condemned by a successor of Pope Clement IV and he was imprisoned.

Johann Gutenberg (*1397–1468*) is credited with the invention of printing. Without such a means of recording and broadcasting scientific work, certainly the growth of science would have suffered greatly.

Copernicus (*1473–1543*) was born on the Vistula and studied in the universities of Vienna and several Italian cities. He was particularly adept at mathematics and he directed this talent toward the development of astronomy. He made some astronomical observations, but his great achievement was the Copernican theory of our solar system. Astronomy had developed relatively little since Ptolemy 1300 years earlier, but it was destined to a radical change. He, himself, realized the heresy of his views and rather haltingly propounded the theory that the planets including the Earth revolve in circular orbits around the sun. Perhaps as a diplomatic stroke he dedicated his work to Pope Leo X.

The work was not written in a manner readily grasped by those untutored in science and, furthermore, a preface was prepared apparently for the purpose of disguising the issue and of removing the edge from the radicalism. This monk was a great influence in mathematics and astronomy and his name will live forever in the annals of science.

William Gilbert (*1544–1603*), an English physician, is best known for his studies of magnetism. He discussed electricity and magnetism not only in relation to small magnets, but assumed the Earth to be a magnet. He tried to account for its rotation as being due to its magnetism. He originated the term *vis electrico* from which our word *electricity* arose.

Tycho Brahe (*1546–1601*), a son of a noble Danish family, is said to have become interested in astronomy through observing an eclipse. He was able to provide himself with the best

instruments that could be made at that time. His greatest contribution to astronomy was through his many keen observations which were so helpful to Kepler and others. He did not follow the ideas of Ptolemy, but likewise he was strongly opposed to the Copernican theory. He determined the length of the year within one second of its true value. He concluded that comets were not atmospheric phenomena and that they revolved around the Sun in an eccentric orbit.

Francis Bacon (*1561–1626*) was primarily a philosophic writer. Through his scientific writings he did much for science. Such men as Bacon and Descartes are largely responsible for driving out some of the dogmas by broadcasting the newer knowledge.

Galileo (*1564–1642*) is one of the greatest men in science. We find him in the midst of a group of men who made noteworthy contributions to science. He made experiments with falling bodies and proved that their speed was independent of their weight. This defeat of an old erroneous doctrine did much to encourage scepticism of the older theories. Science needed badly to be freed from dogmas. He experimented with the pendulum and determined the law of its period of vibration. He studied the paths of projectiles. With his new telescope he revealed new celestial bodies. He showed that the Moon's surface was rough like the Earth's. His support of the Copernican theory must have been an inspiration to his contemporary, Kepler, but at the same time the publication of his ideas brought down upon him the wrath of the Church. We know of the Inquisition and of his recantation. He was very versatile and extremely active, but above all his open-mindedness is refreshing. He possessed the spirit of modern science.

Kepler (*1751–1630*) was another of this noted group born

in France in the sixteenth century. He early entered the observatory of Tycho Brahe, where with his mathematical and philosophic skill, he made excellent use of the accurate astronomical observations which had been and were being made. His great triumph was the addition of the finishing touches which the Copernican theory needed in order that it would represent the true motions of the planets around the Sun. He replaced the circular orbits with elliptical ones and with the aid of new truths in mechanics he enunciated the famous Kepler's Laws. These were not merely ideas; they were founded upon accurate astronomical observations which they accounted for. They cleared up many discrepancies. His health was poor and he struggled against poverty. The practice of astrology at times kept him from going hungry. For this aid to astronomy we may look more kindly on this gentle fake.

Descartes (*1596–1650*) was an aristocrat well educated. During his service in the French army he pursued his likings for mathematics and philosophy. His great contribution was the invention of coördinate or analytic geometry. He dealt with physics to some extent and added something to calculus which was gradually evolving during this period.

Torricelli (*1608–1647*), a follower of Galileo, is best known for his invention of the mercurial barometer. This grew out of his work on hydrostatics and vacua.

Robert Boyle (*1627–1691*) was born at a time when experimentation had already become recognized as a foundation for philosophy. We can mark the beginning of the seventeenth century as the dawn of the experimental age in science. Chemistry began to replace alchemy. Boyle distinguished between compounds and mixtures. He applied the method of weighing in studying chemical reactions. Boyle's Law of gases is his greatest contribution. According to this law the

product of the pressure and volume of a gas is constant for a given temperature.

Huygens (*1629–1695*) may be considered as marking the real beginning of modern science. He developed mechanics, but his greatest contribution was the wave-theory of light.

Robert Hooke (*1635–1703*) introduced the principle of proportionality between stress and strain in the theory of elasticity. This is known as Hooke's Law.

Isaac Newton (*1642–1727*) was the greatest scientist up to his time at least. He expounded his famous laws of motion. He discovered the spectrum of light and associated the spectral colors with refrangibility. He introduced the idea of inertial mass and related it with the change in motion of a body so as to define the force of gravitation. His work in mathematics was original and may be said to have established infinitesimal calculus. He opposed the wave-theory of light and propounded an emission-theory in which light was assumed to consist of particles.

Leibnitz (*1646–1716*) is not generally known because Newton's activities in England overshadowed all contemporary work. Nevertheless, this German contributed much to mathematics and particularly to calculus.

Halley (*1656–1742*) by applying Newton's laws to the comets found that some of them at least revolved around the Sun in very eccentric elliptical orbits. It had been previously thought that comets were wild irresponsibles of the heavens. Obviously if they revolve in elliptical orbits, they return periodically near the Sun after each journey into far-off space.

Maclaurin (*1698–1746*) produced a systematic treatment of fluxions.

Bernoulli (*1700–1782*) contributed to mathematics and theoretical mechanics.

Euler (*1707–1783*) published many volumes on scientific

subjects, and modern algebra, analytic geometry and calculus owe much to his method of presentation.

Lagrange (*1736–1813*) was another of the great mathematicians of the eighteenth century.

Cavendish (*1731–1810*) marks an era of great interest in chemistry. He discovered hydrogen and studied its properties.

Priestley (*1733–1804*) made the extremely important discovery of oxygen. He found that substances burned more actively in oxygen than in air and that mice lived longer in a vessel containing oxygen than when it contained air. Thus he found that air was only partly oxygen.

Herschel (*1738–1822*) was a German musician whose avocation was astronomy. He developed powerful telescopes with which he discovered Uranus and various satellites of planets. He catalogued many stars and nebulae and determined the movement of our solar system in relation to the rest of the universe. He marks the beginning of modern astronomy.

Scheele (*1742–1786*) independently discovered oxygen and therefore, must be credited with helping to lay the foundation of modern chemistry.

Laplace (*1749–1827*) is one of the great names associated with celestial mechanics. He propounded the nebular hypothesis in an attempt to account for the planets and their relationships with each other.

Rumford (*1753–1814*), born in the United States as Benjamin Thompson, went to England and became Count Rumford. He contributed much to the theory of heat.

Carnot (*1796–1832*) followed up the work of Rumford and laid the foundation of the science of thermodynamics.

Dalton (*1766–1844*) is best known by his law of multiple proportions for chemical reactions. He determined the

weights of substances involved in chemical reactions and concluded that the proportions of the different elements were always the same. He did much to establish the ideas of atoms and of atomic weights.

Thomas Young (*1773–1829*) overcame the objection to the wave-theory of light that shadows were sharp and, thereby, revived the Huygens theory.

Fresnel (*1788–1827*), a French student of optics, discovered that light was diffracted and actually "went round a corner," thus supplying Young with the data needed.

Ampère (*1775–1836*) is one of the first of a group who contributed to early knowledge of electricity. Since Gilbert's work with magnetism little advance had been made. He enunciated the law that two parallel conductors, in which electric currents flowed in the same direction, attracted each other, but when the currents flowed in opposite directions they repelled each other.

Oersted (*1775–1851*) discovered that an electric current flowing in a wire attracted or repelled a magnet, depending upon the position of the magnet in relation to the conductor.

Gauss (*1777–1855*) studied magnetized and electrified bodies.

Davy (*1778–1829*) experimented much with electric sparks and arcs, thereby laying the foundation for great developments in electric science. His versatility is shown by the fact that he developed the miner's safety lamp. By surrounding the flame with a metal gauze, a flame light-source could be used with safety in the gas-laden atmosphere of mines.

Faraday (*1791–1867*), who was a pupil of Davy's, developed the science of electromagnetism and electrodynamics. He discovered that magnetism is a universal property of all substances. He conceived the idea of *lines of force* in explaining the effects of magnetic fields and discovered that

current was induced in a closed conductor when it cut a magnet field. He also discovered the fundamental law of electro-chemistry.

Bunsen (*1811–1899*) played a part in the development of the spectroscope and in establishing spectrum analysis. He worked with Kirchoff along these lines. Nothing has revealed so much of the hidden world of atoms as the spectroscope.

Joule (*1818–1889*) made a thorough study of the relation of kinetic energy and heat. He determined the mechanical equivalent of heat; that is, he ascertained that a definite constant amount of work was required to produce one calorie which is the amount of heat required to raise the temperature of a gram of water one degree Centigrade.

Clausius (*1822–1888*) is generally credited with founding the kinetic theory of gases in its present form. Joule had contributed much toward its foundation. The idea of molecules of elements was now firmly rooted.

Kirchoff (*1824–1887*), besides his work in spectroscopy, enunciated certain principles underlying the laws of radiation from warm bodies.

Lord Kelvin (*1824–1907*), who was Wm. Thomson, was one of the very active scientists of the modern period. He established the principle that total energy is constant, but it is dissipated in other forms of energy. He showed that "perpetual motion" was impossible.

Events of the Electrical Age

At this point it seems that the reader will gain a better idea of the progress of scientific development, if the chief events are listed chronologically. We have arrived at the stage where fundamental principles of electrostatics and electromagnetics

were established. Something was known of electrochemistry. This knowledge was the foundation of an *electrical age* in science, for electricity and electric forces were to become interwoven into nearly every phase of science.

William Weber (*1804–1891*) in 1856 discovered an electrical constant which was equal to the velocity of light. This was a startling relationship which was very suggestive.

Julius Plücker (*1801–1868*) in 1859 discovered cathode rays — electrons traversing a low-pressure tube of gas from the negative to the positive terminal.

Joseph Loschmidt (*1821–1891*) in 1865 made a determination of the size of molecules.

Mendeléeff (*1834–1907*) in 1870 discovered the periodic law of elements. He arranged the elements in tabular form in the order of increasing atomic weight and found a striking recurrence of physical properties which were similar for elements in a group. Certain vacancies were left in the table. These were predictions that unknown elements existed. Some of these predictions have been verified by discoveries of the elements.

Clerk-Maxwell (*1831–1879*) in 1873 developed mathematically the electromagnetic theory of light which was far-reaching.

Henry Rowland (*1848–1901*) proved that a moving electric charge possessed the properties of an electric current.

Josef Stefan (*1835–1893*) in 1879 discovered an important law of radiation. According to this law the emissive power of a black-body is proportional to the fourth power of its absolute temperature.

J. J. Thomson in 1881 developed the idea that mass is electromagnetic in origin.

J. J. Balmer in 1885 discovered that certain lines of the hydrogen spectrum could be arranged in a series, the succes-

sive frequencies being so systematically different that they could be computed from a simple equation.

Heinrich Hertz (*1857–1894*) in 1888 produced electric waves experimentally, thereby confirming Maxwell's electromagnetic theory. He also discovered that ultraviolet radiation falling on a spark-gap reduced the voltage necessary to cause a spark to jump across. This was a forerunner of the discovery of photoelectricity.

Wilhelm Wein in 1893 discovered the displacement law of radiation. According to this law the wavelength of maximum emissive power of a black-body is proportional to the reciprocal of the absolute temperature.

Hendrik A. Lorentz in 1895 formulated the electron theory.

Wilhelm C. Röntgen (*1845–1923*) in 1895 discovered the wonderful rays which bear his name.

Henri Becquerel (*1852–1908*) in 1896 discovered the spontaneous emission of electrically charged particles and gamma rays by elements. This phenomenon became known as radioactivity.

The *Curies* in 1898 isolated radium.

Max Planck in 1900 formulated the quantum theory and the general law of radiation.

Ernest Rutherford in 1900 discovered thorium emanation and other radioactive elements in the now well-known series. In 1902, he and *Frederick Soddy* propounded the theory of atomic disintegration.

J. J. Thomson in 1904 introduced his atomic model consisting of orderly arrangements of electrons and a large spherical nucleus charged with positive electricity.

Albert Einstein in 1905 propounded the epoch-making principle of relativity; introduced the theory of light-quanta; and enunciated the law of the inertia of energy.

Walther Nernst in 1906 introduced a new theorem of heat.

Albert Einstein in 1907 applied quantum theory of heat to solid bodies.

Hermann Minkowski (*1864–1909*) in 1908 conceived a four-dimensional universe in which space and time are connected.

Max von Laue in 1912 discovered the interference of Röntgen rays.

W. H. Bragg and W. L. Bragg in 1913 revealed the structure of crystals.

Henry Moseley (*1888–1915*) in 1913 established the far-reaching Röntgen-spectroscopy and discovered a natural series of the elements to which atomic numbers are applied.

Niels Bohr in 1913 introduced a theory of atomic structure based on the quantum theory.

Albert Einstein in 1915 extended the principle of relativity to a general theory of relativity. He and de Haas experimentally revealed the existence of molecular electric currents.

Arnold Sommerfeld in 1915 modified the Bohr model of the atom so that it explained the fine structure of the spectral lines of hydrogen and helium.

Ernest Rutherford in 1919 by bombarding nitrogen atoms with alpha particles showed that hydrogen nuclei were produced. This suggests that the hydrogen nucleus is a part of the nitrogen atoms and of other atoms. He proposed an atomic structure of relatively small nucleus.

F. W. Aston in 1919 discovered isotopes of various elements; that is, that some elements are composed of atoms of different atomic weights, but having identical properties.

R. A. Millikan in 1920 extended the ultraviolet spectrum experimentally to overlap the Röntgen-ray spectrum.

In the foregong outline many important events in physical scence are not included. Space does not permit a complete outline to be presented and what is included is a matter of

judgment. The more this list is reviewed the more inadequate it appears. The experimentalists perhaps suffer unduly by omission, because it has been the aim to include the more foundational material. This is usually theory based on the data which the experimentalists supply. The names of contributors of valuable experimental data would appear often in a complete outline which included this phase of physical science on an equal footing with theoretical physics. Some names have been included largely for the purpose of giving a picture of the connecting links between the entries of theories on the stage of science.

Chapter XVI

UNITS AND MAGNITUDES

Although units have been defined and magnitudes have been presented throughout the text, it may be helpful to assemble a few important ones for convenient reference.

General Units

The *velocity of light* is about 2.999×10^{10} cm. per sec. or 186,000 miles per sec. in a vacuum.

A *light-year* is the distance light travels in a year. It is 5.87×10^{12} miles or 5.87 million million miles.

One *inch* equals 2.54 centimeters.

One *gram* equals 0.0353 ounce (avoirdupois).

One *million* $= 1{,}000{,}000 = 10^6$

One *billion* $= 1{,}000{,}000{,}000 = 10^9$

One *millionth* is 10^{-6}

One *billionth* is 10^{-9}

One *electrostatic* unit equals that electric charge which exerts a force of one dyne on a like charge at a distance of one centimeter.

One *electromagnetic* unit of quantity of electricity is 2.999×10^{10} electrostatic units.

A *coulomb* is the amount of electricity which passes through a solution of silver nitrate for each 0.001118 gram of silver deposited on the cathode or negative terminal. It is one ampere-second or the quantity of electricity represented by one ampere flowing for one second.

Planck's constant h is 6.55×10^{-27} erg-seconds.

A *quantum of energy*, hn, is equal to Planck's constant h multiplied by the frequency n of the radiant energy.

A *calorie* is the amount of heat required to raise the temperature of one gram of water one degree Centigrade. It is equal to 4.2×10^{7} ergs.

A *foot-pound* is the amount of energy required to raise a pound weight one foot. It is equal to 1.36×10^{7} ergs, or 0.324 calorie, or 1.36 joules.

A *joule* is 10^{7} ergs or one watt-second.

A *watt* is a unit of power necessary to raise one gram one centimeter in one second and is equal to a volt-ampere (assuming no phase difference).

One *horse-power* equals 550 foot-pounds per second, or 746 watts, or 7.46×10^{9} ergs per second, or 746 joules per second, or 178 calories per second.

The *kinetic energy* of a body equals $1/2\ MV^2$, where M is the mass of the body and V is its velocity.

Acceleration is the change in speed of a moving body and, therefore, is measured in terms of unit velocity per second or in terms of unit distance per second per second.

The *acceleration* of a body due to the Earth's attraction is 980.6 cm. per sec. per sec. or 32.18 feet per sec. per sec. This is termed the Earth's gravitation constant and is generally represented by g. These values are average for sea-level.

The *weight of a body* on Earth is equal to Mg, where M is the mass and g is the Earth's gravitation constant.

Force is determined by the acceleration a it will impart to a body of mass M. It is equal to the mass times the acceleration. $F = Ma$.

The *velocity of a freely falling body* at the Earth is equal to $\sqrt{2gh}$, where g is the gravitation constant and h is the height from which it has fallen from a state of rest.

Electron

Its mass is 8.9×10^{-28} gram at velocities less than 1/10 that of light.

Its charge is 4.77×10^{-10} electrostatic units.

Its charge is 1.59×10^{-20} electromagnetic units.

Its charge is 1.59×10^{-19} coulombs.

Its diameter is perhaps about 3.2×10^{-13} cm.

One ampere equals a flow of 6.3×10^{18} electrons per second.

Proton

This is the unit of positive electricity and its mass is equal to that of the hydrogen atom.

Hydrogen Atom

Its mass is 1.66×10^{-24} gram at velocities less than 1/10 that of light.

Its mass is 1840 times that of an electron.

It apparently contains only one electron.

Its diameter is perhaps about 1.1×10^{-8} cm.

Its atomic weight is 1.008, that of oxygen being 16.

Other Atoms

Their masses are as many times greater than that of the hydrogen atom as their atomic weights are greater than 1.008. The diameter of the helium atom is probably about 2×10^{-8}.

The diameter of the heaviest atom — uranium — is perhaps about 2–1/2 times that of the hydrogen atom.

Nuclei of Atoms

They perhaps consist of hydrogen nuclei.

The mass is practically that of the atom itself.

The diameter of the nucleus of the hydrogen atom is about 2×10^{-16} cm. or about 1/1800 that of the electron.

The diameter of the nucleus of a gold atom is perhaps about 2×10^{-12} cm.

Molecules

The mass of a molecule of hydrogen is 3.3×10^{-24} grams.

The mass of any molecule is as many times greater than that of hydrogen as indicated by its molecular weight relative to hydrogen.

The diameter of the molecule of hydrogen is 2.17×10^{-8}cm.

The diameter of the molecule of oxygen is 2.99×10^{-8} cm.

The diameter of the heaviest molecule (uranium) is perhaps about 2–1/2 times the size of the hydrogen molecule.

There are 2.7×10^{19} molecules in a cubic centimeter of gas at atmospheric pressure and at the temperature of melting ice.

A *gram-molecule* or *mole* of a substance is the number of grams equal to the sum of the atomic weights of all the atoms in a molecule of the substance.

A *mole* of any gas under the standard condition of pressure (atmospheric) and of temperature (melting ice) occupies a volume of 2.24×10^{4} cm. (about 0.8 cubic foot) and contains 6.06×10^{23} molecules.

The mean velocity of hydrogen molecules under standard conditions of pressure and temperature is 1.69×10^{5} cm. per second or about one mile per second. Heavier molecules travel slower, their velocities being equal to that of the hydrogen molecule (under the same conditions) divided by the square root of their molecular weight relative to that of hydrogen taken as unity.

The *mean free path of molecules* of a gas is the mean distance travelled between collisions. Under standard conditions of pressure and temperature the mean free path of hydrogen molecules is 1.6×10^{-5} cm. When the pressure is decreased the mean free path is increased. Hydrogen molecules collide about 10^{10} or ten billion times per second.

The *average kinetic energy of a molecule* of gas under standard conditions of pressure and temperature is 5.6×10^{-14} erg.

The Solar System

The approximate diameters of the bodies of our solar system and the mean radii of their orbits are as follows:

	Diameter of Body	*Radius of Orbit*
Mercury	3,000 miles	36 million miles
Venus	7,700 "	67 " "
Earth	7,900 "	93 " "
Mars	4,200 "	142 " "
Jupiter	86,500 "	483 " "
Saturn	73,000 "	886 " "
Uranus	31,900 "	1782 " "
Neptune	34,800 "	2971 " "
Moon	2,163 "	240 thousand miles
Sun	866,400 "	....

The Universe

The diameter of the known universe is at least 35,000 light-years and perhaps three times as great. The approximate distances of some of the stars from the Earth are as follows:

	Light-Years
Sirius	9
Vega	35
Arcturus	43
Capella	49
Polaris	76
Rigel	466
Small Magellan Cloud	32,600
Star Cluster in Hercules	100,000?

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